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# Pantteg Landslip

# Data Review and Management Proposals

Earth Science Partnership
Consulting Engineers | Geologists | Environmental Scientists
🖃 33 Cardiff Road, Taff's Well, CARDIFF, CF15 7RB ☎ 029 2081 3385
✉ enquiries@earthsciencepartnership.com www.earthsciencepartnership.com

# Pantteg Landslip
# Data Review and Management Proposals

Prepared for:
Neath Port Talbot County Borough Council, The Quays, Brunel Way,
Baglan Energy Park, Neath, SA11 2GG

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| 00 | Final | September 2016 | M R Eynon<br>BSc (Hons) MSc CGeol EurGeol FGS RoGEP Specialist | M A O'Neill<br>PhD PGCert BEng (Hons) CEng MICE FGS RoGEP Adviser | G S J Sommerwill<br>BSc (Hons) MSc CGeol FGS RoGEP Specialist |
| | | Signature: | | | |
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# Summary

The Pantteg landslip is part of a larger landslip system located to the southwest of Ystalyfera in the Swansea Valley, South Wales. Land movements continue to have significant impacts on the local population and infrastructure. The aim of this assessment is to establish an understanding of the historical and current Pantteg landslip conditions, hazards and risks, such that options for the future management of the landslip can be considered.

Twenty-six landslip events have been recorded in Pantteg since the earliest records and it is likely that there have been many more. The form and frequency of these events varies, however it appears that there is often a link between high rainfall and instability. The most recent large ground movement in 2012 blocked the road opposite Pantteg Chapel and caused disruption for a long period.

The underlying geology of the area comprise superficial Glacial Till, Colluvium, Alluvium and rocks of the Middle and Upper Coal Measures strata which includes the Llynfi Sandstone, Llynfi Mudstone, various coal seams and seat earths.

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.

Observations during the autumn of 2015 conclude the landslip system is the same general condition encountered during 2013. However, tension cracks appear to have increased in size, material appears to be falling from the steep southern slopes, some properties have been reoccupied and deformation of structures has been noted. A mine tunnel has been identified on historical data; the entrance of which has been identified close to Clees Lane.

No incidents of loss of life have been recorded over time; however, we believe that this was only narrowly avoided on a number of occasions. Preliminary quantitative risk assessment has highlighted a level of risk to life and property which is generally not tolerated. In addition, larger ground movements are currently unpredictable and have potentially serious consequences to life and property, which increases the sensitivity of the site.

Previous assessments have concluded that the overall landslip system could not be economically stabilised and we concur with this opinion. With the absence of a feasible engineering remediation strategy, the overarching future aim is to create a suitable management system and possible early warning system that enables decisions and reactions to emerging conditions and environmental factors.

The reliability of this early warning system will depend heavily on long term monitoring and assessment of the resulting data. This will require investigation and research into the links between the ground, rainfall, river flow and movements/changes to the geomorphology of Pantteg to enable the formulation of a quantitative assessment and management approach.

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# 1 Introduction

## 1.1 Background

Earth Science Partnership Ltd (ESP) have been commissioned by Neath and Port Talbot County Borough Council (the Client) to undertake a geotechnical assessment of the Pantteg Landslip. The landslip is part of a larger landslip system the origins of which can be linked back to the last Ice Age; it is located to the southwest of Ystalyfera in the Swansea Valley, South Wales. The associated land movements continue to have significant impacts on the local population and infrastructure.

The wider landslide system has been the subject of several historical investigations and assessments and the following reports have been supplied to ESP by the Client and provide the primary basis for this report. Additional information has been reviewed from a University of Portsmouth MSc thesis. These sources are listed below:

- Godre'r Graig & Pantteg Landslides, Report on Hazard Mapping, report for the Lliw Valley Borough Council by Sir William Halcrow and Partners, July 1987.
- Pantteg Landslide, Report on Ground Investigation, report for Lliw Valley Borough Council by Sir William Halcrow and Partners, December 1989.
- Pantteg and Godre'r Graig Landslide Area, Report on Assessment of Landslide Hazard, Neath Port Talbot County Borough Council, February 1998.
- Pantteg and Godre'r-Graig Landslips Slope Stability Review, Jacobs Engineering UK Limited, December 2013.
- 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.

## 1.2 Site Location and Description

The site is located on the north western side of the Tawe Valley near the town of Ystalyfera which is approximately 21km northeast of Swansea. The National Grid Reference of the site is SN761081 and the postcode for Pantyffynnon village located to the south of the site area is SA9 2DQ. A map extract showing the geographical location and topographical setting is presented as Figure 16 (appended). The general topography in the area is of a valley nature. The base of the valley is near the A4067 which was constructed adjacent to the old Swansea Canal. The River Tawe flows south towards the coast at the base of the valley.

The valley side rises up to the 'old' valley road (Graig Road/Cyfyng Road) and becomes progressively steeper as the upper road is neared. Numerous dwellings and structures are present to the east and west of Cyfyng Road. The valley side steepens above Cyfyng Road to a gradient of about 1v:2h to an elevation of about 150mOD where the slope becomes shallower to the summit. Old quarries are present to the west and various light industry is present to the north.

The Pantteg landslip is part of a wider landslip system present on the slopes of the hill known as Mynydd Allt-y-grug. The wider landslip (which includes the Godre'r Graig landslip and other areas of unnamed movements) covers an area of approximately 54 hectares. The Pantteg landslip occupies around 18 hectares of this. The western, or upper, extent of the Pantteg landslip is defined by a series of inactive quarries. The eastern, or lower, extent of the Pantteg landslip is not easily defined as there is an interface with a landform dating from glacial actions locally; however modern movements seem to be restricted to a slope toe that is approximately equidistant between the main road through Pantteg village (Cyfyng Road) and the A4067, which lies at the base of the Tawe Valley. The northern extent of the Pantteg landslip is to the north of Graig y Merched. The southern extent is defined by the interface with the Godre'r Graig landslip.

The upper parts of the landslip are typically undeveloped, while the lower areas (eastern), closer to the valley floor, have been developed with housing over time. Some of the houses are occupied; however, there are areas where houses have been abandoned due to safety issues linked to ground movements.

For continuity with existing assessments, the approximate boundary between the two landslip areas is taken to be at the junction of Graig Road, Pantteg Road 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 Penygraig House, as illustrated in Figure 1: Extract from the 1:25,000 scale Ordnance Survey Map showing the approximate extents of the Pantteg (green) and Godre'r Graig (yellow) landslips (reproduced under OS licence 0100015788). Not to scale.

The precise boundary between the two landslips will be more complex, and there is likely to be some interaction between the two landslip areas.

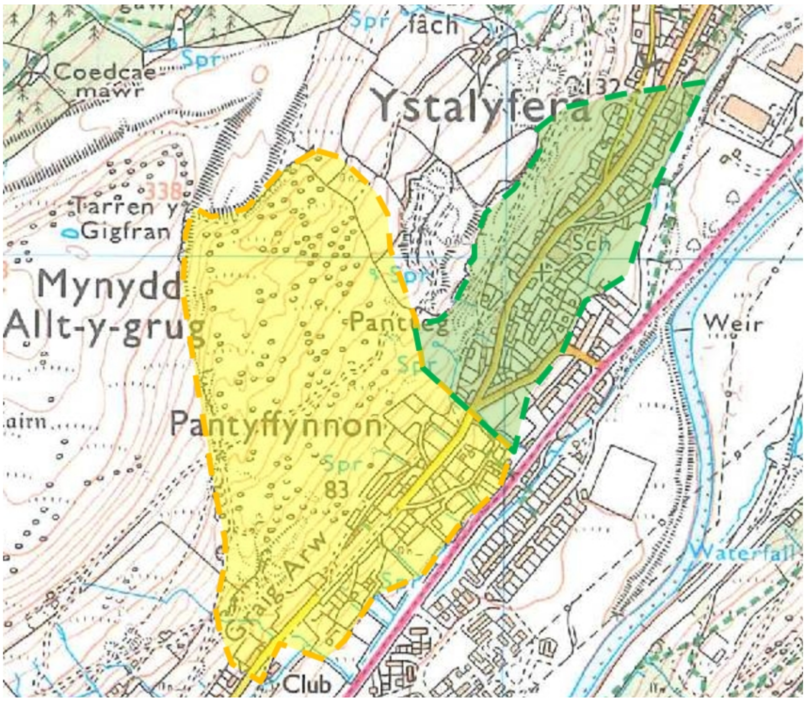
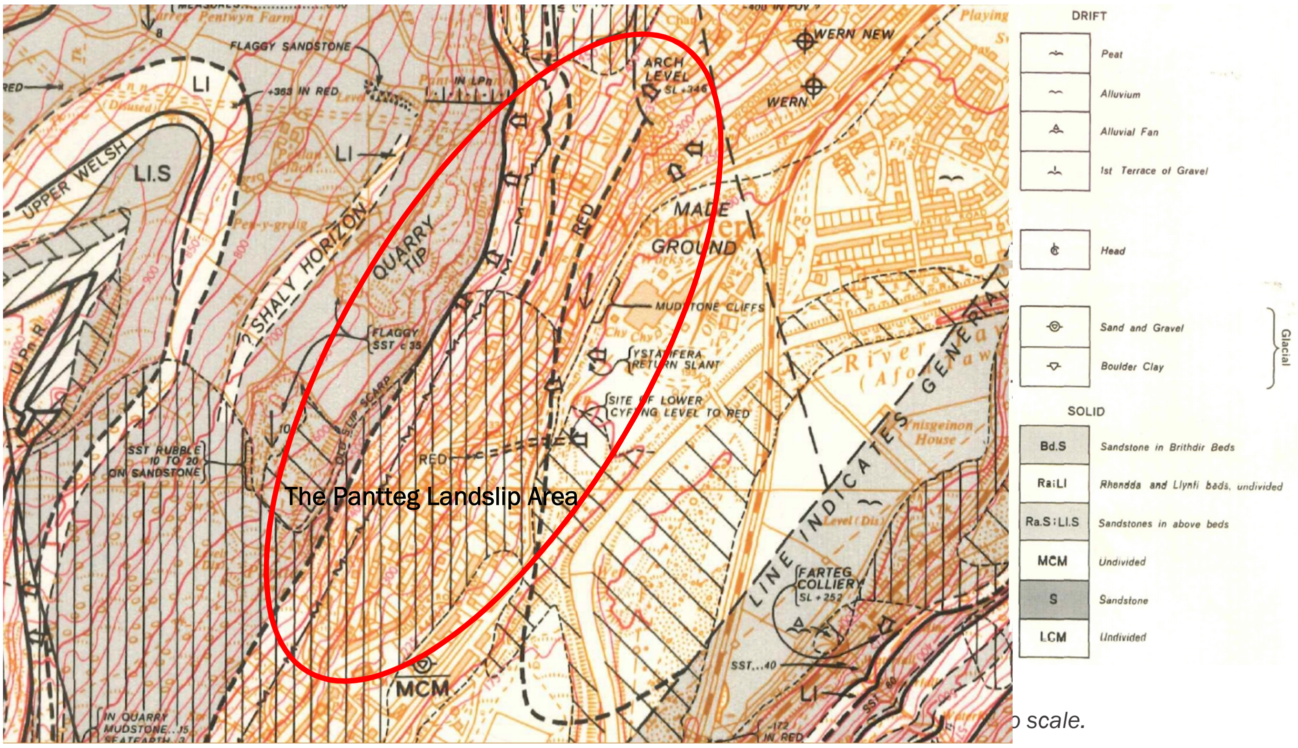


*Figure 1: Extract from the 1:25,000 scale Ordnance Survey Map showing the approximate extents of the Pantteg (green) and Godre'r Graig (yellow) landslips (reproduced under OS licence 0100015788). Not to scale.*

## 1.3 Regional Geological Setting

The wider landslip system, of which the Pantteg landslip is part, is considered historically as the total area of the Godre'r Graig landslip, above the village of Pantyffynnon, and the total area of the Pantteg landslip, above the village of Pantteg, and some other related but unnamed and unmapped land movements in the immediate vicinity of the two named landslips.

The geological mapping data available from the BGS (SN 70 NE), of which an extract is shown in Figure 2, shows the underlying superficial geology of the area to comprise superficial Glacial Till, Colluvium and Alluvium. The solid geology is shown to comprise the rocks of the Middle and Upper Coal Measures strata which can be expected to be made up of cyclothems that includes the named strata: the Llynfi Sandstone, Llynfi Mudstone, various named and unnamed coal seams and unnamed strata including seat earths. The dip of the solid geology is generally to the south at approximately 10° though notable and significant local variations exist.



o scale.

The wider landslip has evolved since the end of the last ice age from ancient deep seated rotational landslips within the rock and subsequent shallow rock and soil failures. The geology, mining and landslip are considered further in Section 3.

## 1.4 Aims, Objectives and Scope of Works

The aim of this assessment is to establish an understanding of the historical and current Pantteg landslip conditions, hazards and risks, such that options for the future management of the landslip can be considered.

To achieve this the following objectives have been derived:

- Review of previous reports and information;
- Update the assessment of the current conditions;

- Critically review the existing risk assessments and methodologies;
- Establish a basis for future management of the risks;
- Recommend possible tools and strategies for future management;
- Make preliminary assessment of the benefits and implications of the recommendations.
- Present a ground investigation strategy to aid risk quantification for the future management strategy.

The terms of reference for the assessment are as laid down in the Earth Science Partnership proposal of the 16th April 2015 and subsequent letter of the 23rd February 2016.

# 2 Review

## 2.1 Previous Assessment Reports

The earliest geological mapping of the area is dated 1897 and identifies the area of the Pantteg Landslip as being a ‘landslipped area’. It is apparent that the area is likely to have been subject to unrecorded movements prior to and since this date. There has been documented history of ongoing instability since 1946 in local press and older technical reports and it is likely that other modern movements have gone unremarked or recorded.

A number of previous reports were commissioned by the Lliw Valley Borough Council and Neath Port Talbot County Borough Council took over responsibility for the area in 1996, the purposes of each are described below:

- Report on Hazard Mapping, report for the Lliw Valley Borough Council, July 1987. This included a summary of instability, ground movements and what was known about the geology at that time.
- Report on Ground Investigation, report for Lliw Valley Borough Council, December 1989. This report included information from site specific ground investigation works within the Pantteg landslide area, resulting in the production of geological cross sections of the area.
- The 1987 and 1989 reports produced the original Hazard and Risk assessment plans.
- Pantteg and Godre’r Graig Landslide Area, Report on Assessment of Landslide Hazard, February 1998. A review was carried out in 1997 and 1998 which included a revised Hazard and Risk Zonation Map and report.
- Pantteg and Godre’r-Graig Landslips Slope Stability Review, December 2013. This was produced following a landslip in December 2012.

## 2.2 Site History

### 2.2.1 Review of Pantteg History

An understanding of the site history has been gained from a review of historical Ordnance Survey maps, previous reports and discussion with the Client. Extracts from the historical maps are presented in Appendix A and, where considered useful, information from previous reports has been incorporated in to the main text.

Features and trends have been identified and discussed in the historical map review below, directly related to the Pantteg landslip and wider landslip system. Evidence of individual properties becoming abandoned or destroyed have been included, where appropriate.

#### *2.2.1.1 General Development and Evidence of Instability*

The earliest map studied, dated 1877, shows Ystalyfera, Pantteg and Pantyffynnon to have been developed.

The road that extends the length of the wider landslip system was the former main road through the valley (the A4068). Based on discussions with the client, instability of the valley side at Pantyffynnon and Pantteg resulted in the diversion of the road to a new alignment on the valley floor.

Evidence of ruins, possibly the result of ground instability, can be seen at various locations and points in time. The historical map excerpt reproduced as Figure 3 shows a ruin along Clees Lane in an area of known historical instability.

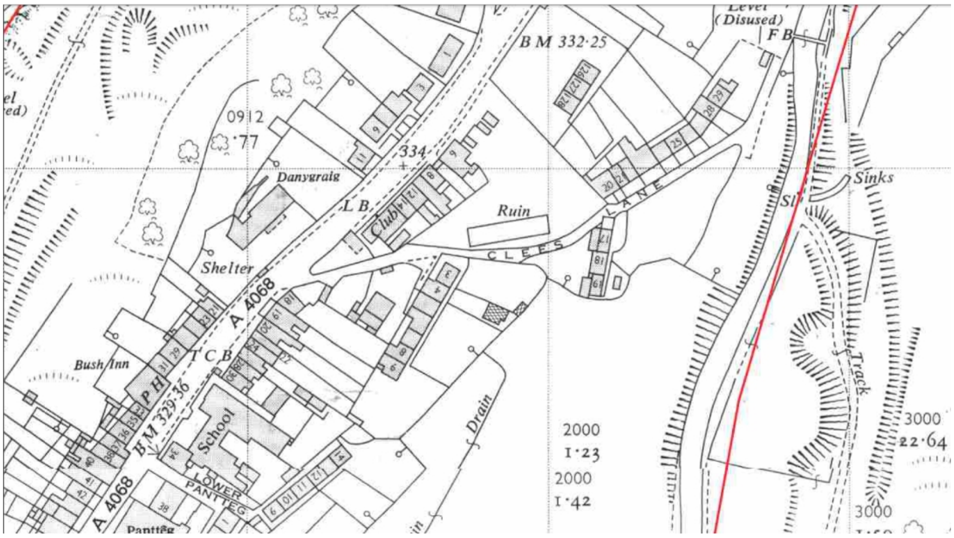


Figure 3: 1960 Historical Map

The villages at Pantteg and Pantyffynnon (the village historically present to the south) were constructed on the steep valley sides above the valley floor.

The landslips recorded in 1946 and subsequent movements have led to the destruction of most of Pantyffynnon, and houses not demolished by ground movements have generally been abandoned; the road through the centre of Pantyffynnon was blocked off to prevent vehicle use. The remaining habitable houses are all below the old road.

The village of Pantteg has also been affected by ground movements, and the majority of the properties to the north-west of the road have been abandoned and or demolished due to ground movements. There are a few remaining properties, extending from the Chapel to Graig y Merched in Pantteg. The historical map excerpt below shows houses demolished on Graig y Merched following an earlier landslip (believed to have occurred in 1986).

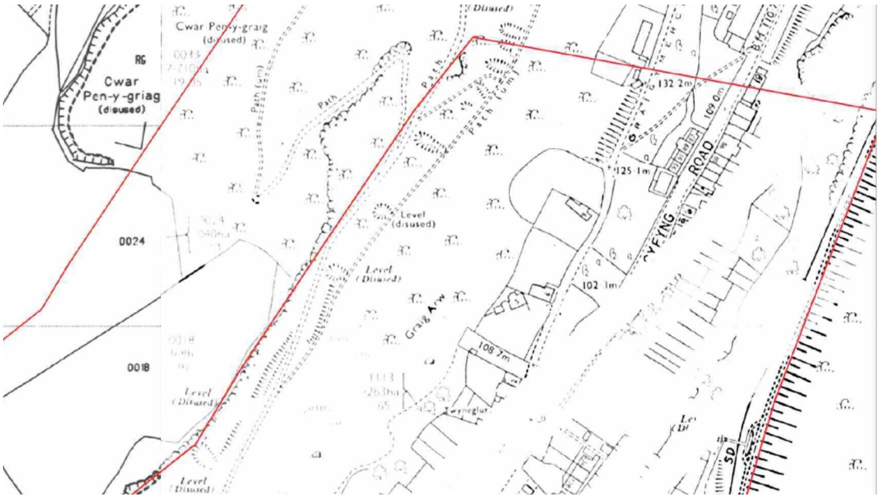


*Figure 4: 1993 Historical Map Excerpt*

The areas to the east (i.e. downhill) of the old valley road are known from previous assessments consist of a fan of colluvial material. Much of this material has been built upon, the properties primarily being newer dwellings.

### *2.2.1.2 Mining and Quarrying Features*

Much evidence and records exist of the historical coal mining beneath the area of the wider landslip system. Quarrying of sandstone has occurred above the landslip system (within Cwar Pen-y-graig-arw) and is believed to provide a local supply of building materials.

There are several old coal levels recorded on the site, mostly to the west of Pantteg and Pantyffynnon. The 1918 Ordnance Survey map records two coal levels to the east of Clees Lane in Pantteg. An excerpt, shown in Figure 5, of the historical map of 1960 provides an example of the evidence of mining above Graig y Merched in disused levels.

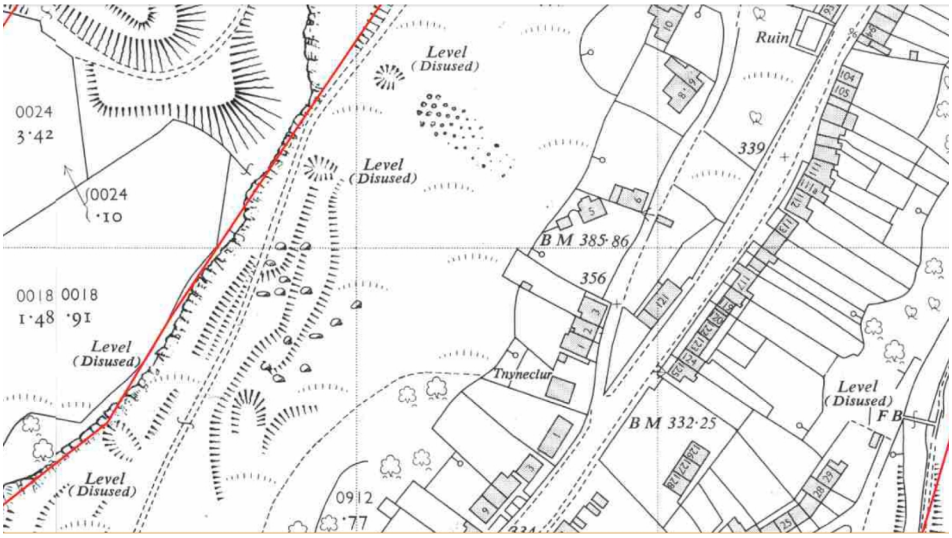


*Figure 5: 1960 Historical Map Excerpt*

No mining or quarrying is currently occurring and the quarries are not listed within the British Geological Survey Directory of Mines and Quarries (2014).

### 2.2.1.3 *Hydrological and Hydrogeological Features*

Numerous springs and issues are identified throughout the historical evidence. Approximately 8 springs and surface water features are shown within the described bounds of the Pantteg landslip area. The mapping information consulted indicates that they are in a relatively static location, however there is a notable change in the amount and position of springs between maps dated 1918 and 1960 across the wider landslip area. The reason for this is unclear but could be attributed to either changes in local hydrology, ground movements or changes in the standards and methods used in the mapping of features.

An excerpt of the historical map of 1960 provides an example of the evidence of springs, issues, sinks above Cyfyng Road in Pantteg, and is shown in Figure 6.

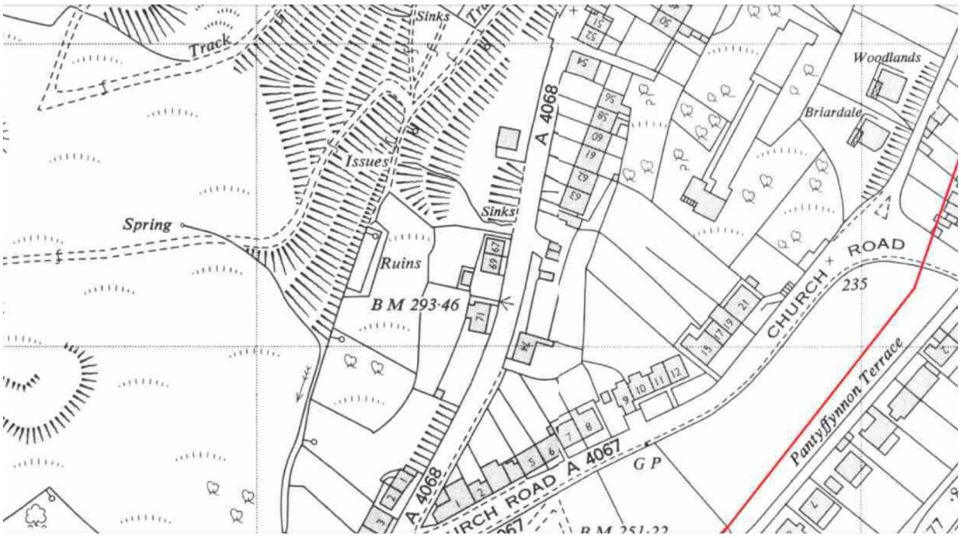


*Figure 6: 1960 Historical Map Excerpt*

The historical and most recent Ordnance Survey mapping indicates a number of springs across the wider landslip area. Previous assessments considered that these may be old coal mine entrances and the ‘springs’ are drainage points of mine water from adits. It should be noted that mine water is often acidic and therefore be a source of contamination.

## 2.3 Timeline and Events

A timeline and description of the various events at and linked to the Pantteg and the wider landslip system has been collated from the various sources cited herein. The events described are from across the wider landslip area so as to present a clearer understanding of the scale of the various ground movements.

### 2.3.1 Timeline of Known Events

The following table shows known events across both landslip areas in chronological order with a brief description.

| Event No. | Date | Description of Event |
|---|---|---|
| 1 | 1/01/1897 | Landslide noted on Geological map. |
| 2 | 01/01/1946 | Soil moving in garden of No. 8 Mount Hill into road as a result of disruption to drainage in nearby quarry. |
| 3 | 01/01/1946 | 71 Mount Hill - soil sliding onto road. |
| 4 | 01/02/1951 | Boulders falling from steep slopes above Mount Hill on to garden of 39 Graig Road. |
| 5 | 01/08/1954 | Torrential rain forced three houses to be evacuated at Twyncerdinen. Not know if due to mud flow or just flooding. |
| 6 | 01/06/1955 | Movement in hillside and retaining wall in junction of church road and Graig road - cracks in retaining wall. |
| **7** | **01/10/1957** | **Thousands of tons of mud blocked 100m of A4068. Movement at the time attributed to quarry drainage.** |
| 8 | 02/10/1957 | Cracks noted in retaining wall to rear of 41-49 Graig road/church road junction. |
| 9 | 01/11/1957 | Threat of boulder slide at 45 Mount Hill. |
| **10** | **01/12/1959** | **Major incident to No.60 to Golden Lion Pub on Graig Rd, single line traffic on A4068 and 24 inch water main disturbed over 70 yards.** |
| 11 | 01/11/1964 | Boulder noted threatening Pantteg. |
| 12 | 01/05/1965 | New Road opened by Local Authority as a result of December 1959 landslide. |
| **13** | **19/12/1965** | **At Pantteg, 'excessive water, surface and subsoil forced the fissured earth to fall'. Further boulders were in 'imminent danger of falling'. Graig Road was blocked by 15ft of soil. Pylons were tilting and cracks were evident on Graig Road.** |
| 14 | 01/05/1967 | Local Authority offered to buy 32 affected houses. |
| **15** | **01/10/1967** | **Further movement of road where previous water main damage occurred.** |
| 16 | 06/11/1967 | Continued spreading of landslides and described as 'incurable' in large meeting. 40 houses warned of dangerous place to live. Decided to investigate to determine if remedial measures were possible. |
| 17 | 21/11/1968 | Dangerous boulders present at Pantteg school. |
| 18 | 01/10/1974 | Drainage scheme completed - no major movements in early 70s. |
| **19** | **22/01/1975** | **Movement behind 41-48 Pantteg (Mount Hill). Considerable flow of water occurred introducing fresh cracks and movement behind the school which was subsequently closed.** |
| 20 | 01/09/1975 | Water falling over the face of the Pantteg quarry sank with the ground, missing the drainage system. |
| 21 | 01/06/1979 | Additional drainage work completed. |
| 22 | 01/03/1981 | Minor surface slides by Bush Inn, no damage. |
| 23 | 01/06/1983 | Properties adjacent to the Bush Inn were demolished and area was landscaped. |
| 24 | 19/03/1981 | Two minor landslips. |
| **25** | **19/11/1986** | **Rotational slump at north end of Pantteg, 6 houses affected and another slide effected road.** |
| **26** | **22/12/2012** | **Landslip blocked roadway between Penygraig House and Pantteg Chapel.** |
| Notes: **Bold text denotes Major Event** | | |

*Table 1: Chronological Order of Events*

Relevant information on significant historical ground movement events at the Pantteg landslip and wider landslip system is provided in the subsequent sections.

### 2.3.2 Landslips from 1946 to 1967

The first recording of active movement in the twentieth century for the site dates from January 1946 when soil from the garden of No. 8 Mount Hill, Pantteg, slid onto the road in front and resulted in disruption of the drainage system from Pen-y-Graig Quarry.

The image from an undated postcard reproduced as Figure 7 below shows the general arrangement of the area of Pantteg Chapel, hall, slope toe morphology and historical properties. The image shows the uneven/hummocky slope in its previous form and properties, which are now demolished, on the left.

*Figure 7: Undated Postcard of Pantteg Chapel (Ball, 2015)*

The earliest recorded example of loose boulders on the steep slopes found (dating from February 1951) related the area above Mount Hill in Pantteg and the boulders were recognised as threatening houses below, the record was made following a boulder fall into the back of the property at number 39 Graig Road, Pantteg. A number of other boulders were then later removed.

In August 1954 torrential rain gave sufficient rise in concern to see three houses evacuated at Twyncerdinen, just above Mount Hill, because of water and mud from the land above the houses. It is not known whether this was a landslip or the result of flooding.

In June 1955, movement of the hillside and retaining wall at the junction of Church Road and Graig Road was noted, however specific details are not recorded.

A serious incident occurred on 29th October 1957 when about 100m of the former route of A4068 was blocked near Mount Hill by mud, rocks and trees. Three houses were damaged and telephone and electricity cables were destroyed. The failure appeared to have been relatively rapid and the road was blocked for four days. At the time of these incidents, the primary cause was attributed to a quarry drainage system. It was believed by some that the restoration of the Tirgarw Opencast site in 1954 had promoted additional run-off into the northern side of the landslide, which eventually reached the quarry drainage. At the same time new tension cracks were noted behind 41-49 Graig Road at Pantyffynnon, which was an early warning to a more damaging event in December 1959.

The first major incident at Pantyffynnon village occurred on 10 December 1959. Landslide and the continued threat to the Graig Road, saw plans being drawn up to construct a new road away from the threat of damage caused by the ground movements of the area and a new road following the line of the Swansea Canal on the valley floor was constructed and opened to traffic in May 1965.

A further series of major incidents occurred after the weekend of 17th to 19th December 1965. A landslip caused water, soil and an earth slope to fall and a debris flow travelled through 43 and 44 Pantteg which were unoccupied at the time. 41, 69 and 71 Mount Hill and 41 Pantteg were immediately evacuated. Further boulders were in imminent danger of falling.

In the southern part of the Pantyffynnon village, 93 Graig Road and a Council lorry were destroyed by a landslide on 19th December 1965. The road was blocked to a depth of 15ft (approximately 3m). Further movement of the road in Pantyffynnon was reported in October 1967.

### 2.3.3 Landslips from 1968 to 1985

A drainage scheme was completed in October 1974 and was reported to have improved the situation locally to an impressive degree. Although further movements occurred at Pantyffynnon in the wider landslip area since that time.

On 22nd January 1975, the Pantteg area suffered further movement behind No. 41-48 Mount Hill and also new movement in the adjacent slopes toward the Bush Inn. Considerable flows of water occurred, some of which cascaded down to the slope behind No.43 Mount Hill and through the house itself to flood the main road to half its width. The steep slopes behind the houses showed pronounced evidence of movement with fresh cracks and large boulders were moving slowly down the hillside. As a result of this incident, Pantteg School was closed. No.41 to 48 Pantteg were evacuated and No.33 to 40 were later abandoned by their owners.

In September 1975, it was noticed that water falling over of the face of the quarry at Pantteg sank with the ground, missing the drainage system and re-emerging downslope saturating the ground above Penygraig House.

Throughout this period, the Pantteg Residents Association advocated that drainage could reduce the risk of further landslides. This view was communicated to the Local Authority and additional drainage was recommended, including removal of some boulders and planting of vegetation to protect bare soil, which was completed by 1979. Further movements behind the Bush Inn at Pantteg were reported on 19th March 1981 where ‘two areas of minor surface landslip’.

### 2.3.4 Landslips from 1986 to present

On 19th November 1986, two incidents occurred at the northern edge of the Pantteg landslip, a rotational slump of superficial deposits and associated outbursts of water and debris damaging three houses, numbers.1, 2 and 6 Craig y Merched and it also affected a further three other houses. An apparent blockage of the drainage pipe installed by the council in 1979 cause debris to wash down onto the road and drive of 95 Graig Road.

A significant amount of ground movement was observed to the east and north-east of Penygraig house in the two years prior to December 2012. This apparently coincided with severe weather experienced in the area over two preceding winters and wet summer of 2012.

The most recent significant landslip occurred on 22 December 2012, and affected an area of Pantteg between Penygraig House and Pantteg Chapel, as shown in Figure 8. The landslip blocked the road at Pantteg Chapel, and partially blocked the road opposite 49 Pantteg. Access to Penygraig house was severed.

*Figure 8: Landslip at Pantteg Chapel, December 2012, (Website accessed November 2015)*

Following the 2012 landslip, the Client sought advice on appropriate remedial works at the site. The works undertaken comprised clearing the failed material from the highway and slope back to rockhead allowing the creation of a drainage ditch and berm at the foot of the slope, and a run-out area opposite the chapel. The works included the demolition of Penygraig House following the discovery of tension cracks up-slope of the house, and structural distress to the property.

The failure had also resulted in the partial destruction of pipework for a mine drainage system in the vicinity of Penygraig House and this is understood to have been remediated.

he remedial works were to remove the immediate risk from the unstable material, to make the site safer and to reduce the risks that might be associated with further failure immediately upslope of the road and not to prevent any future slope failure.

The work supporting the strategy for the remediation work to address the failure states that it was difficult to identify the cause of the failure. Postulations on cause are offered and include contributions from naturally oversteep slopes, low strength superficial materials, leakage from the mine drainage system, collapse of old mine workings, preferential groundwater flows from the coal seams and extended periods of heavy rainfall through 2012.

# 3 Ground Model

## 3.1 The Geological Environment

The Tawe Valley was subject to over-steepening, whereby an eroding glacier steepens the sides of a pre-glacial valley, during the last glaciation period. Reference to geological memoirs, engineering journals and published records hold information on the Pantteg landslip (e.g. Conway et al, 1980). The geological setting has been introduced in Section 1.3.and this has resulted in areas like and including that around Pantteg being susceptible to landslides.

It is known that the landslip is a large complex slip with slumping at the head above debris slides and flows. Some degraded flows are seen at the toe on the valley floor.

The upper part of the landslip is in the Upper Coal Measures Llynfi sandstone with some Llynfi shale associated with the Upper Welsh coal seam. Movement has largely been rotational grading into debris slides.

The lower part of the landslip is in the Middle Coal Measures shale below the Llynfi sandstone, with the Lower Pinchin coal outcropping at the junction. Recorded movements are largely debris slides and flows with slumping of Llynfi sandstone above the coal seam, movement was reported to be largely confined to this part of the slip. In some parts of the slip, thick superficial deposits are present.

## 3.2 Physical Information and Site Investigation

Despite the long history of instability in the area around Pantteg, the amount and detail of information from intrusive site investigation is limited, amounting to four boreholes across an area of around 18Ha This may be in part be due to access steeply sloping topography, density of vegetation and landslip morphology. The level of investigation information available is considered inappropriate and does not adhere to the guidance presented in various documents, including Eurocode 7, 2004.

Boreholes were sunk using cable percussive and rotary drilling at four locations during July and August 1989 to establish the geological sequence, ground and groundwater conditions. Trial pits were excavated in ten locations. Three standpipe piezometers were installed in the boreholes to provide information on groundwater within the rock and landslide deposits beneath the hillslope. The piezometers were subsequently monitored at weekly intervals.

The locations of the boreholes and trial pits are shown on Figure 17 (appended). None of the groundwater monitoring wells now exist or can be located having been destroyed by subsequent ground movements or vandalism.

## 3.3 Geology

The geology at the site was largely confirmed in the site investigation carried out in 1989 and the ground conditions are summarised in the following sections. The investigation work confirmed the regional geology Reference is made throughout this section to investigation positions which were made in the previous investigation and assessment reports, the positions of which are shown on Figure 17 (appended). A Generalised Cross Section is presented as Figure 20 (appended).

### 3.3.1 Superficial Geology and Landslide Materials

Deposits within the upper landslide area, shown on Figure 20 (appended), comprise approximately 8m of landslide deposits of gravel, cobbles and boulders of angular siltstone and sandstone debris with a loose silty sand matrix. The trial pits also encountered gravel, cobbles and boulders of weathered siltstone and sandstone, but with little matrix and an open structure; these materials are interpreted as the remnants of displaced rock produced by rotational sliding of one or more blocks of the Llynfi Rock at the horizon of the Lower Pinchin Seam.

Deposits within the lower landslide area, shown on Figure 20 (appended), comprise approximately 4m to 6m of landslide deposits of sandstone cobbles and boulders and fine sandstone and siltstone gravel with a loose silty sand matrix. These are also interpreted as the remnants of displaced rock. These deposits were very poorly recovered in the boreholes. No slip surfaces were noted.

Glaciofluvial deposits are present on the Valley floor and Alluvium is also present.

### 3.3.2 Solid Geology

As outlined in Section 1.3, the sequence of rock strata within the hillslope consists of a succession of sandstones, siltstones and claystones of the Middle Coal Measures and the overlying Llynfi Beds of the Upper Coal Measures, the junction between which is defined by the Upper Cwmgorse Marine Band. These strata dip southwards at about 10 degrees which produces an effective dip of a few degrees toward the base of the valley.

The upper part of the slope is dominated by thick, strong, thinly to medium bedded sandstone which outcrops in the cliff that forms the backscarp of the Pantteg landslip. The sequence contains many thin developments of moderately weak to moderately strong, thinly laminated siltstone in its upper part (collectively referred to as the Llynfi Rock).

Beneath the sandstone, a 13m thick sequence containing three leaves of the Lower Pinchin Seam is present. Previous reports indicate that the lowest 1m seam was mined.

Between the Lower Pinchin Seam and the next named seam, the Lower Welsh, which crops at the foot of the slope behind the village, investigation proved about 38m of moderately strong, laminated arenaceous siltstone with about 10m of weak to moderately weak claystone and a thin coal in its central portion. It is understood that the Upper Cwmgorse Marine Band lies within these claystones but evidence of this was limited. Beneath these strata, the Lower Welsh seam is present, followed by clayey siltstone and a fissured seatearth which is approximately 2m thick.

The 90m thick sequence described above, which forms the hillslope above the village, is underlain by further Middle Coal Measures which are believed to be mainly siltstones and claystones. The Red Vein, which has been worked from levels in the valley floor, notably from levels next to the air shaft, occurs about 30m beneath the Lower Welsh Seam. A Conceptual Ground Model is presented as Figure 20 (appended) and Table 2 summarises the solid geology at the site.

| Group | Member | Named Horizons | Comments |
|---|---|---|---|
| Pennant Sandstone Formation (Upper Coal Measures) | Rhondda Member | Sandstone | |
| | Boundary Horizon | No.2 Rhondda | Coal Seam (Mined) |
| | Llynfi Member | Sandstones / Siltstones / Claystones | |
| | | Upper Pinchin | Coal Seam (Mined) |
| | | Sandstones / Siltstones / Claystones | |
| | | Upper Welsh | Coal Seam (Mined) |
| | | Sandstones / Siltstones / Claystones | |
| | | Llynfi Rock | Sandstone (Quarried) |
| | | Sandstones / Siltstones / Claystones | |
| | | Lower Pinchin | Coal Seam (Mined) |
| | | Siltstone | |
| Marine Band | Boundary Horizon | Lower Cwmgorse Marine Band | |
| Middle Coal Measures | | Mudstone | |
| | | *Thin Coal* | Adit found opposite Pantteg Chapel |
| | | Siltstone | |
| | | *Thin Coals* | |
| | | Lower Welsh | Coal Seam (Mined off site) |
| | | Siltstone | |

*Table 2: Solid Geology Sequence*

A north-south trending fault is shown on the published BGS map. The fault is roughly located along the western boundary of the Godre'r-Graig landslip (the wider landslip system).

## 3.4 Topography and Geomorphology

The general topography in the area is of a valley nature, the base of the valley is near the A4067 which was constructed adjacent to the old Swansea Canal. The valley side rises up to the 'old' valley road (Graig Road/Cyfyng Road) and becomes progressively steeper with increased elevation.

The valley side steepens above the 'old' road to a gradient of about 1v:2h to an elevation of about 150mOD where the slope becomes shallower to the summit. The Pantteg Landslip area terminates at a line of cliffs approximately 100m to 120m from the road, the foot of the cliffs being at approximately 170mOD.

The main topographical and geomorphological features at the site have been observed and recorded during site walkovers during October and November 2015.

There are four distinct benches or breaks of slope between the valley floor and the crest of the cliff, as shown on Figure 20 (appended).

From recent observations, instability is confined to shallow strata, within superficial deposits (mainly on the first and second benches), as shown on the General Cross Section presented as Figure 20 (appended).

Features of instability are present at the Pantteg landslip, such as:

- Landslip backscarps (Figure 9);

*Figure 9: Landslip backscarps above Pantteg Chapel*

- Displaced blocks;
- Debris slides and debris flows;
- Landslip lobes (Figure 10);

*Figure 10: Landslip lobes along Clees Lane*

- Rotational slumps;
- Accumulation zones.
- Tension cracks (Figure 11);

*Figure 11: Tension cracks above Pantteg Chapel*

The western cliff line is considered the rear scarp of the upper landslide system formed as a result of rotational failures between the Llynfi Rock and the less competent underlying rocks.

Rotational movements are inferred downslope within material displaced by the upper landslide (that extend to the base of the valley).

A series of Plates illustrate a number of the geomorphological features. The landform has changed since assessments in the 1980's, 1990's and most recently in 2013. Further discussion on the landslip geomorphology is presented in Section 4 based on historical studies, recent visits and observations.

## 3.5 Mining and Quarrying History

Section 3.3 provides a summary of the general and coal-specific geology of the area which has been exploited on an industrial scale over the last two or three hundred years. It is likely that further smaller scale exploitation of coal has occurred over a much longer period. Historical Coal Mining

Abandoned mine plans were examined as part of work carried out in previous phases of work looking at the Pantteg landslip and its wider landslip system. However, no detailed consideration has been made of the impact on stability. Previous assessments indicated that coal mining at Pantteg and the wider landslip system was restricted to relatively shallow seams beneath or adjacent to the landslides. In descending stratigraphic order, these are:

- No.2 Rhondda (or Ynysarwed Seam);
- Upper Pinchin (or Mountain Seam);
- An Unnamed Seam;
- Lower Pinchin Seam;
- Lower Welsh Seam;
- Red Vein.

There is evidence that the No.2 Rhondda (or Ynysarwed Seam), Upper Pinchin (or Mountain Seam), Lower Pinchin Seam and the Red Vein were worked at shallow depth beneath the landslides from levels driven into the slope. Siddle (2000) provides a summary of the mine drainage and states that the mines had gravity drainage systems that collected groundwater and conveyed it to the adit mouths.

The Lower Pinchin Seam, Lower Welsh Seam and Red Vein are present beneath the hillslope at Pantteg.

Findings relating to coal mining beneath the site are described in the following sections and incorporate information assessed from Coal Authority mine abandonment plans in 2016 (as part of report revision 1), where available. The abandonment plans are presented in Appendix B. The abandonment plans for the Upper Pinchin seam have not been assessed as this coal outcrops away from the landslip area.

#### 3.5.1.1 *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 abandonment plans are available at present.

#### 3.5.1.2 *The Lower Welsh or 'Welsh' Seam*

It was not clear previously if the Lower Welsh Seam has been mined beneath the site. It was understood that this seam 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).

#### 3.5.1.3 *The Red Vein*

The Red Vein was probably the earliest seam to be worked systematically in the area. The Lower Cyfyng Level was probably active from the 1830's onwards, during which time the north and central areas of the wider landslip 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 landslip 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 to 306ft AOD (58m to 93m) 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 (129mAOD) to 232ft (70mAOD). These elevations match the ground levels of a mine entry opposite the chapel and a mine entry identified off Clees Lane. This supports the theory of a conduit existing between these points and is discussed further in Section 3.5.2.

### 3.5.2 Mine Entries and Infrastructure

A series of adits are shown on Figure 18 (appended), and this has been formulated from information within the historical assessments and other information sources (such as the Coal Authority). The adits are linked to the out crop of the Lower Pinchin Seam in the upper portion of the landslip system. Mine entries are also indicated further downslope and are linked to the Red Vein.

The Coal Authority have designated Development High Risk Areas across the coalfields of the UK. These areas are linked to the underlying geology and presence of coal. The shallower the coal, the more likely a site is to lie within a high risk area. The coal outcrops at Pantteg and the associated high risk areas are shown below:

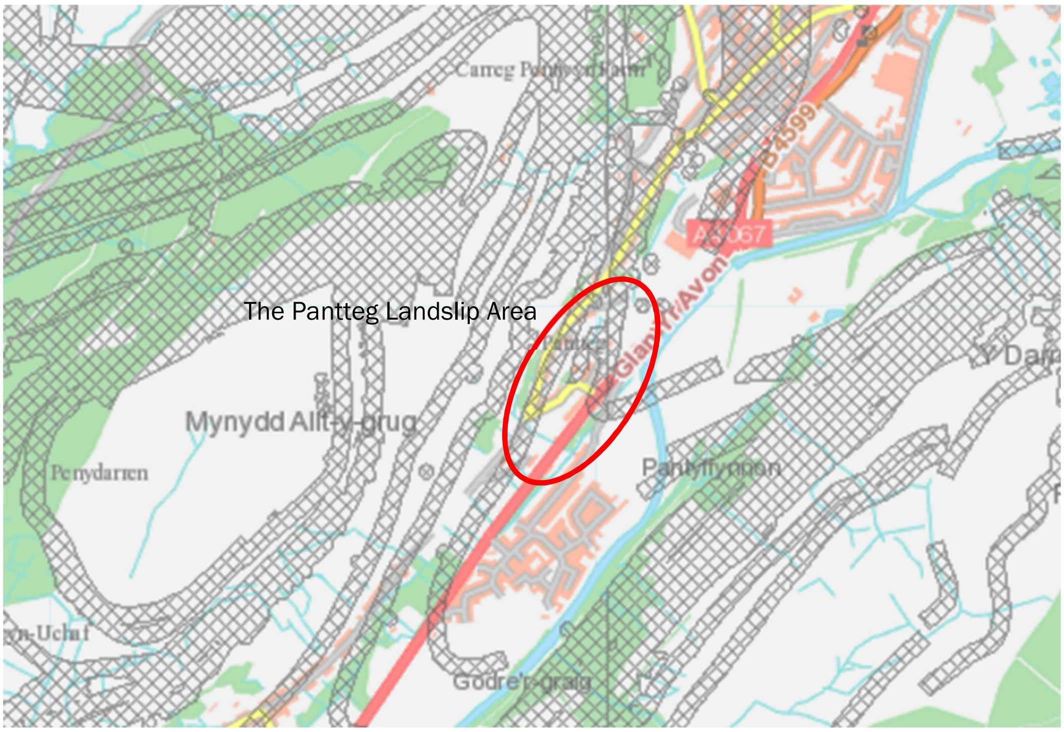


*Figure 12: Coal Authority Development High Risk Area (Coal Authority, 2015)*

We have been provided with a plan by NPT CBC entitled Landslips and Godre’r Graig and Pantteg – Information and Record of Incidents Since 1955 (Ref: Drg No. M2). On this plan, the approximate line of a tunnel is shown, the eastern portal of which correlates with the mine entries indicated at this location. This feature is also shown on Figure 2 and its presence is supported by the evidence on the abandonment plans. During our recent walkover survey at Pantteg, it has been possible to identify this feature and this is presented as Plate 11.

From the plan, the western portal of this tunnel is indicated at Mount Hill, to the north of the now demolished Penygraig House. Based on discussions with NPT CBC and from site observations, it is possible that the concrete construction linked to the tunnel feature is now visible in the slope opposite the chapel, see Plate 13. However, it is possible that the physical construction/headworks may have been displaced downslope during the 2012 instability or subsequent regrading works.

### 3.5.3 Quarrying

Two quarries are indicated on the earliest available historical map of 1877 to the west and north west of the Pantteg landslip. On the 1899 map the northernmost quarry is named Cwar Pen-y-graig and the southernmost quarry is named Cwar Pen-y-graig-arw. It is believed that the quarries extracted the Llynfi Sandstone for local aggregate and building materials.

Evidence of the following can be seen on the mapping data:

- Rock slopes;
- Quarry spoil slopes;
- Tracks.

The location, features and extents of the quarries are shown below.

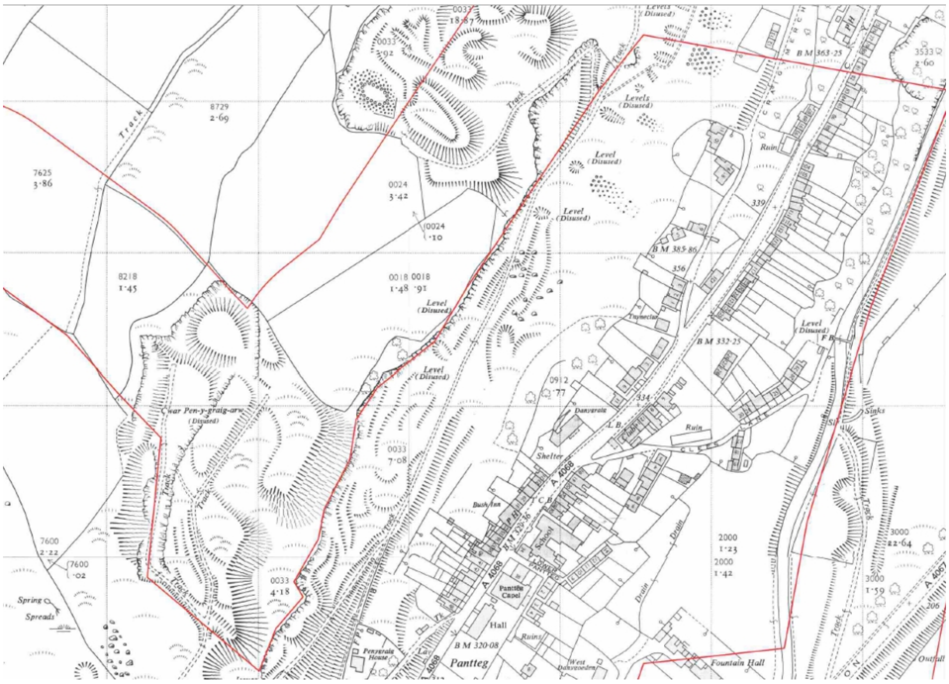


*Figure 13: 1960 Historical Map Excerpt*

No quarrying is currently occurring and the evidence suggests quarrying ceased prior to 1960. From the recent site visit numerous mounds of spoil/discard are present within Cwar Pen-y-graig and is shown on the enclosed Plate 12. Access to Cwar Pen-y-graig-arw was restricted by heavy vegetation.

## 3.6 Hydrology and Hydrogeology

A series of discreet natural and man-made surface water features are present at Pantteg and across the wider landslip area. These features serve to collect and transmit surface water downslope and collect/input water to the ground. These features are described in the following sections.

### 3.6.1 Surface Waters and Surface Drainage

Identified and mapped surface water features are presented as Figure 19 (appended), Hydrology and Drainage. The nearest major surface water feature to the site is the River Tawe whose main channel is in the valley floor and flows southwards.

As mentioned in the site history, three surface drainage systems, comprising large diameter pipe systems were installed during the 1950's and 1960's. These mainly drain water from the adits draining the Lower Pinchin seam. The three systems are explained further in the following sections.

#### 3.6.1.1 *The Cilbrwyn Drainage System*

A formal drainage system exists in the wider landslip area, across the hillside above the backscarp of the Godre'r-graig landslip (which forms the wider landslip area). Although some interactions will occur, the Cilbrwyn system is not considered to have a direct effect on the Pantteg landslip itself.

#### 3.6.1.2 *The Church Road Drainage System*

The church Road System collects the outfall from two adits on the hillside above the junction of Church Road and Graig Road. The water is directed under Graig Road to emerge as a stream that flows along the southern edge of the Cemetery. The adits appear to have accessed the Lower Pinchin seam. It is believed that this drainage pathway has been in part influenced by construction and diversion of surface waters.

It has been noted that there is a flow of water over and through the retaining wall on the uphill side of the Graig Road at this location, indicating that either the drainage system is leaking into the surrounding ground, or that the ground at this location is already saturated (from other sources) and the drainage system is not dealing with this. The Church Road Drainage System is shown on Figure 19 (appended).

#### 3.6.1.3 *The Penygraig Drainage System*

The Penygraig drainage system is a network of pipes carrying surface water runoff and spring water and mine water from Cwar Pen-y-graig-arw (sandstone quarry) and mine entries. The catchment area for the system is the floor of the quarry, two adits to the west of the quarry entrance, and the cliff face to the rear of the former site of Penygraig House.

A main carrier pipe then descends the steep slope to the west of the Penygraig House site, to outfall into the highway drainage system on Mount Hill, opposite No.56 Pantteg. The adit drains are all related to the elevations of the Lower Pinchin coal seam.

In September 1975 it was noticed that water falling over of the face of the quarry at Pantteg sank with the ground, missing the drainage system and re-emerging downslope saturating the ground above Penygraig House.

The alignment of the pipeline within the sandstone quarry was traced in 2013 by the presence of inspection chamber covers. However, it was not possible to inspect the alignment east of the path due to the density of vegetation cover. Site clearance may be required to achieve accurate delineation. If all the surface waters are not captured and diverted through the drainage system, it is possible that the quarries are permitting infiltration into the underlying strata, therefore enhancing instability during periods of high rainfall.

The section where the pipe flows down the slope of the Pantteg Landslip was severed and partially destroyed during the December 2012 failure. This section has been repaired and reinstated as part of the 2012 site works, which also resulted in the demolition of Penygraig house.

Following the 2012 slip remedial works were implemented, which briefly comprised clearing the failed material from the highway and slope back to rockhead where possible. Only material that had failed in 2012 and in the two years previous was removed. This allowed the creation of a drainage ditch and berm at the foot of the slope, and a run-out area opposite the chapel. The Penygraig drainage system is shown on Figure 19 (appended).

From recent walkovers of the site further formal drainage is present along and above Graig y Merched, as shown on Plate 14. It is likely that the presence of natural and semi-natural drainage pathways (i.e. those present as a result of ground-movement) are present across the Pantteg landslip and efforts should be made to identify these where possible.

### 3.6.2 Groundwater

#### *3.6.2.1 Influencing Factors*

The hydrogeology of the landslide is dominated by the Llynfi Rock (predominantly sandstone and arenaceous siltstones) which overlies the Lower Pinchin coal. Given that these sandstones crop over an extensive area uphill and, structurally up dip of the landslide, there is the potential for groundwater to flow into the landslide from the base of these strata. It is considered that this unfavourable geological configuration is one of the main factors contributing to the ancient initiation of instability. It has been found that the groundwater catchment has a relatively thin cover of superficial deposits and that the quarries immediately uphill of the landslide are especially receptive to infiltrating rainfall. It is possible that the quarries are permitting drainage into the underlying strata and enabling transmission into the unstable areas, therefore enhancing instability during periods of high rainfall.

The main groundwater bearing unit beneath the site is the Lllynfi Rock (sandstone). The remainder of the Upper and Middle Coal Measures strata will act as aquifer units. Groundwater movement will be partly controlled by intergranular flow (primary porosity), but is likely to be dominated by flow through discontinuities in the rock strata (secondary porosity). Historical quarrying and coal mining will have a profound effect on the groundwater regime in terms of input and through-flow.

#### *3.6.2.2 Groundwater Investigation and Assessment*

Boreholes were sunk using cable percussive techniques and rotary drilling at four locations during July and August 1989 to establish the ground and groundwater conditions beneath the hillslope. The percussive holes penetrated most of the superficial deposits and the remainder, together with the underlying rock were cored in order to prove the geological sequence beneath the slope. The locations of the boreholes are shown on Figure 17 (appended); however, these positions are now either destroyed by movement or have been vandalised.

The 1989 ground investigation revealed that groundwater has the potential to enter the landslide deposits from both the horizon of the Lower Pinchin Seam and a thin coal above the Lower Welsh Seam.

In the area of the investigation, it was concluded that workings in the Lower Pinchin Seam may preferentially channel water to adjacent areas of the landslide where there was active or recently active movement and this area is believed to have partially failed (with some properties at 21-29 Pantteg now demolished). Adit (mine) entrances are potentially likely areas for groundwater emergence and those at the lowest point of the workings are especially susceptible.

Groundwater has also historically been associated with the area of active movement opposite Pantteg Chapel, where water may be emerging in a concealed fashion from a suspected coal level immediately uphill of the unstable area. However, the presence of landslide deposits may impede the emergence of water and artesian pressures may be present if the sandstones locally are confined by less permeable landslide deposits.

It has been indicated that rainfall drains into the Llynfi Sandstone, which then penetrates down to the underlying Lower Pinchin coal seam. It has been considered that historical mining within the Lower Pinchin coal seam allows concentration of water and preferential drainage along the lines of the adits.

Previous assessment concluded that there was little direct evidence that outflow from the adits in the Lower Pinchin seam were causing significant inflow of water into the landslip. However, the combined flows from the mine drainage system, groundwater seepage line and historical coal mining were identified as major contributory factors in the failures at Pantteg.

It was noted that groundwater emerges from a spring in the rear scarp of the 1986 landslide at Craig-y-Merched. A spring in this location is noted on past editions of Ordnance Survey maps, it was previously suggested that the large flows which accompanied the failure in 1986 were the result of a diverted stream sinking into above quarry the and re-emerging at the issue. It was suggested that flows may have exploited workings in the Lower Pinchin Seam which are known to underlie the quarries. The springs are shown on Figure 19 (appended).

In the lower part of the landslip, groundwater is probably relatively shallow, as seen in the saturated areas at the junction of Church Road and Clees Lane and these are linked to the accumulation zones described in Section 4.

#### *3.6.2.3 Groundwater Monitoring*

Piezometers indicated that there were low water pressures in the landslide deposits in the slope above the properties and that beneath the properties, the landslide deposits are almost fully saturated. No evidence of artesian pressures within the strata was found. Monitoring of piezometers installed in 1989 suggested that groundwater also concentrates along the Thin Coal strata at the base of the claystone band that forms the ledge at the top of the 2013 landslip remediation. It has been indicated that water seepages were linked to rainfall events, confirmed by observations of a seepage line revealed following the regrading works in 2013.

The 1989 investigation installed groundwater monitoring wells which were monitored over four months (August to November 1989). The groundwater levels obtained and head change over the monitoring period is presented below:

| Borehole | Ground Level (m OD) | Maximum water level (m OD) | Minimum water level (m OD) | Head Change (m) | Strata | Comment |
|---|---|---|---|---|---|---|
| BH1a | 189.27 | 160.50 | 156.42 | 4.08 | Lower Pinchin Seam | Maximum reading considered erroneous |
| BH2a | 155.20 | 135.60 | 135.46 | 0.14 | Llynfi Rock | |
| BH2b | 155.20 | 148.300 | 148.26 | 0.04 | Colluvium | |
| BH3a | 130.54 | 111.49 | 108.99 | 2.5 | Siltstone above Lower Welsh Coal Seam | Notable response |
| BH3b | 130.54 | 125.55 | 124.59 | 0.96 | Coal Measures/Colluvium Boundary | |
| BH4a | 100.70 | 98.45 | 96.47 | 1.98 | Base of Colluvium | Notable response |
| BH4b | 100.70 | 99.05 | 97.22 | 1.83 | Colluvium | Notable response |

*Table 3: Summary of Monitored Groundwater Levels, August to November 1989*

From this relatively limited data, the following can be summarised:

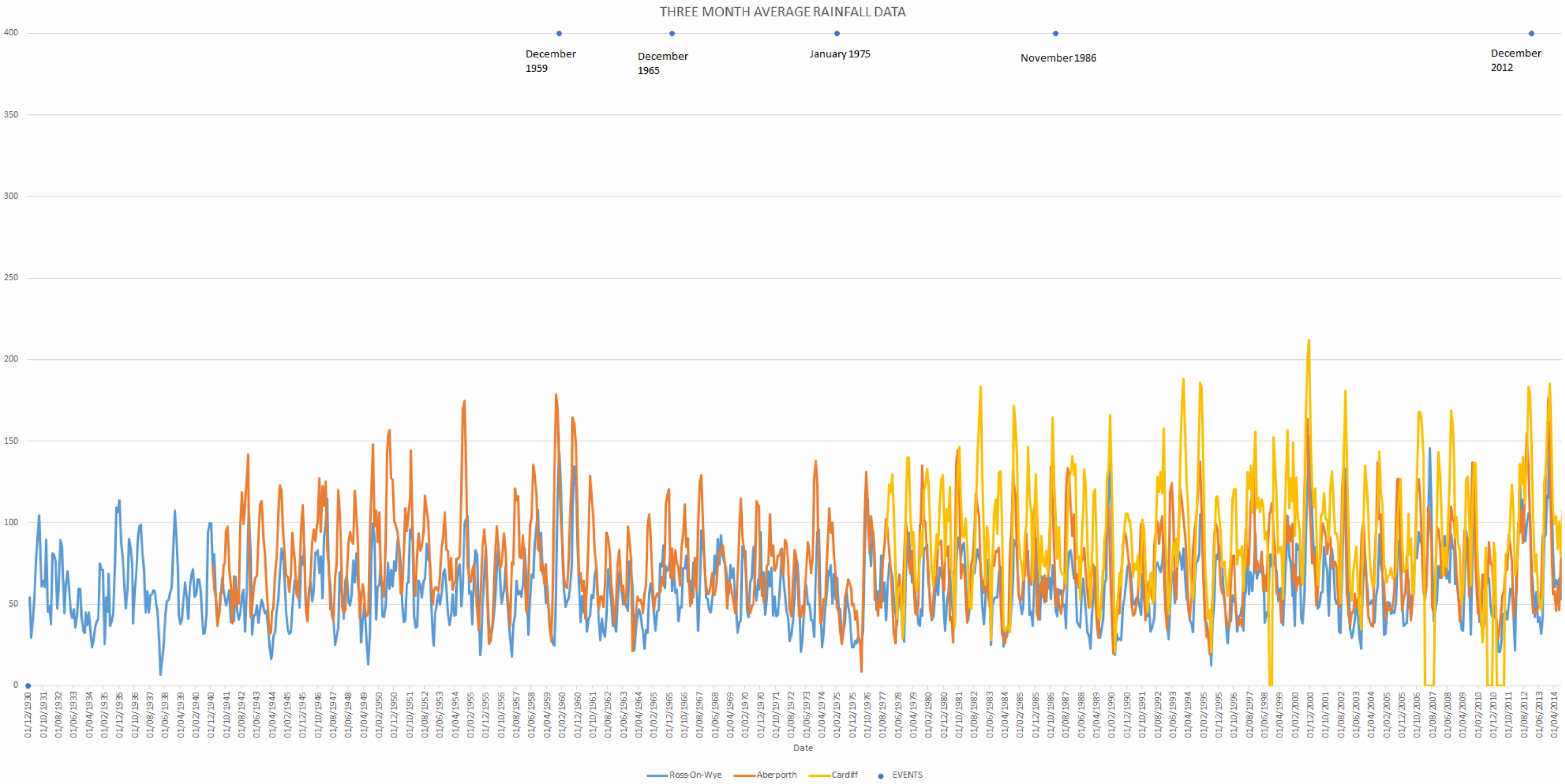
- Groundwater was observed in the Llynfi Rock, Lower Pinchin Seam and the siltstone overlying the Lower Welsh seam.
- A notable response to rainfall was observed in the Lower Pinchin seam itself and in the siltstones above the Lower Welsh Seam (up to ~4m head change). This provides evidence that there is a strata controlled response to rainfall within the groundwater system in the landslip.
- A notable groundwater response was recorded in the colluvium at the toe of the slope adjoining Cyfyng Road. The ~2m head change coincided with a rainfall event that exceeded 50mm/day.
- Less significant responses to rainfall were noted in the upslope areas within the Llynfi Rock and Colluvium.

It is not clear when the monitoring was carried out in relation to rainfall events and it may be that the maximum groundwater levels presented are not fully representative of the system.

### 3.6.3 Rainfall Data

Rainfall data has been obtained from three separate rainfall gauges across Wales; Cardiff, Ross On Wye and Aberporth. Rain gauge from Cwmystwyth has also been obtained and utilised later in this report.

In an effort to explore the link between rainfall, river flow and instability, the following five major events have been selected to enable preliminary assessment of the relationship between rainfall, river flow and landslip events, namely the events that occurred in the following years: 1959, 1965, 1975, 1986 and 2012. These events shown on the following rainfall graph (Graph 1).



*Graph1: Relationship between rainfall, river flow and landslip events: 1959, 1965, 1975, 1986 and 2012*

No significant relationship between landslip events and longer-term rainfall trends has been established. However, for the December 1959, December 1965 and December 2012 events a general increasing rainfall trend is possibly present through the preceding years. Further comparison and discussion of rainfall data, river flow data and instability is provided in Section 4.6.1.

## 3.7 Anthropogenic Influences

Further to recent site visits, additional anthropogenic influences on the landslip and instability have been identified.

The overall construction of the village of Pantteg removing material from the toe of the colluvial slopes and activities on, above and below the slope (e.g. the ongoing modification of houses and gardens) has probably reduced overall stability. This includes regrading works reducing lateral support on marginally stable neighbouring slope areas.

Disruption or uncontrolled modification of the surface drainage systems is also likely to reduce stability. In addition, we have identified a possible groundwater conduit between Pantteg back-scarp area and lower landslide area (Lower Pantteg) via possible mine tunnel identified from historical information. Blockages in this tunnel may reduce stability.

These influences will form part of the consideration of the effectiveness of the management strategies discussed in Section 6.2.

# 4 The Pantteg Landslip

The Tawe Valley is a steep sided former glaciated valley. At Pantteg there are slopes of up to around 40° and vertical back scarp cliffs. In post-glacial times, landslips have occurred at numerous locations across the Pantteg hillslope and wider system.

The landslip at Pantteg is probably an ancient feature and probably dates from the retreat of Devensian ice from the Swansea Valley. Fundamentally, this is a view offered by M. D. Wright and Siddle (2000) who suggests the majority of superficial deposits on the valley slopes of South Wales have been disturbed by the effects of deglaciation and periglacial weathering.

Further to this 'The dominant problem of slope failure in the South Wales coalfield seems to be the reactivation of landslides on old failure surfaces (whether shallow or deep)', W.C Rouse (2000). These are general statements and are obviously not specific to Pantteg but nonetheless have to be acknowledged.

## 4.1 Landslip Morphology and Type

The instability at Pantteg and the wider landslip system is relatively simply defined consisting of rotational movement of blocks of the Lllynfi Beds on failure surfaces within the underlying argillaceous strata associated with the Lower Pinchin coal seam. Disaggregated sandstone blocks and displaced colluvium cover the steep slope immediately downhill and extend as lobes towards the valley base (Siddle, 2000). At Pantteg, the principal mode of failure in recent years is shallow debris sliding of soils on the steep slope behind the village.

The Pantteg Landslip can be defined by two separate systems, an upper and lower system, as described in the following sections. The Upper and Lower Landslip areas are shown on Figure 20 (appended).

### 4.1.1 The Upper Landslip System

The main factors relating to the Upper Landslip System are as follows:

- The upper limit of the Pantteg landslides is the cliff face caused by the outcrop of the Llynfi Rock sandstone.
- There is a dip out of the slope, allowing for the sandstone to fail in planar sliding, as evidenced by the screes at the foot of the cliff. The cliffs themselves are generally near vertical.
- The resulting failed material falls onto the underlying siltstone layer, which forms a downhill sloping terrace below the sandstone cliffs. Currently this is covered in vegetation, suggesting that there have not been any recent falls. The landforms on the terrace also suggest the presence of rotational movements affecting the underlying siltstone units.
- Historical ground investigation works suggest that the base of the failure is controlled by the presence of the Lower Pinchin coal seam, and effectively the failed material that forms the terrace is founded on this base plane.
- Over time the volume of material on the terrace increases, and there is a downslope movement, probably assisted by groundwater emerging along the

basal coal seam, causing the material to descend downslope into the top of the lower system.

### 4.1.2 The Lower Landslip System

The main factors relating to the Lower Landslip System are as follows:

- The lower landslide system extends downslope of the outcrop of the Lower Pinchin coal seam, the backscarp being within a layer of competent siltstone, which appears to form a steep slope above a narrow terrace.
- The terrace appears to be analogous to the outcrop of the claystones containing the Upper Cwmgorse Marine Band.
- Below the terrace a steep slope drops down to the level of the old valley road (Pantteg/Cyfyng Road).
- Failures in the lower system appear to be a combination of shallow rotational movements and superficial deposits sliding off of the underlying bedrock. Failures will be driven by the presence of groundwater, in this case emerging from the Thin Coal seam below the Cwmgorse Marine Band, surface water from the hillslope above and increased loading caused by descent of material from the upper system.

### 4.1.3 Colluvium below Pantteg

Below the old road, there is evidence that the village is built upon colluvial deposits, i.e. material that has failed on the slope above, and come to rest on the lower slopes above the valley floor. This area is likely to be only marginally stable.

## 4.2 Geomorphological Features

The geomorphological features and other characteristics of each landslide element highlighted by Halcrow, Jacobs and by ESP during the autumn of 2015 at Pantteg are summarised in the following table.

The locations of the features are shown on Figure 21 (appended) and within the individual plates referenced.

| Landscape Element / Landslip Process | Morphological Characteristics | Material | Activity | Location/Plan Reference |
|---|---|---|---|---|
| Back scar/cliff line (rockfall) | Free face of sandstone up to 15m high with rockfall scree at base. Some flows of water issue from colluvium/scree covering base of cliff. | Sandstone boulders | Largely inactive | A (Plates 4 & 5) |
| Displaced block (rotational sliding) | Areas where a column of sandstone rock and overlying quarry spoil has slumped carrying sandstone boulders and spoil on to the debris slide below. | Sandstone | Possibly recently active | G (Plate 6) |
| Debris slide (translational sliding) | Hummocky, vegetated and dry, gently sloping terrace. Seepages from toe. | Disaggregated rock debris | Mainly inactive. Area below displaced block possibly recently active | H |
| Rotational slump (rotational sliding) | Previous narrow terrace fronted by a steep convex slope above Graig road and Mount Hill. Area now further north. | Colluvium | The southern half is active or recently active having caused problems since 1946 and most recently in 2012.<br>Lobate landforms, steep angles at juncture of landslip and Church Road. | F (Plate 1) |
| | Ground movement evidenced by telegraph pole movement and apparent slumping of the ground. | Colluvium | Possible movement in south direction (feature north of the 1986 landslide). | N (Plate 9) |
| Debris flow (flow) | Uneven 10 to 20.0m wide tongue of un-vegetated debris with water flowing over the surface. | Colluvium | Flow associated with rotational slump occurred in 1986. | I |
| Accumulation zone (mainly translational sliding) | Moderate slopes, vegetated, lobes, wet ground.<br>Water flowing downslope along Clees Lane. | Colluvium | No evidence of recent movement | B (Figure 10) |
| Tension Cracks | Area above 2012 landslide shows tension cracks which are apparently recent. | Sandstone | Evidence of recent movement | J (Plates 6 & 7) |
| Anthropogenic Factors | Mine / Tunnel Entry | N/A | | C (Plate 11) |
| | Quarries Upslope | N/A | | D (Plate 12) |
| | Remediated Zone / Rock Berm | N/A | | E (Plate 3) |
| | New Gully/Drainage | N/A | | K (Plate 13) |
| | Retaining Wall below Graig-y-merched. | N/A | | L |

*Table 4: Geomorphology modified after autumn 2015 Site Walkover*

## 4.3 Interaction with adjacent slips/ground

The boundary between the two landslip 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 Penygraig House.

The precise boundary between the two landslips will be more complex, and there is likely to be some interaction between the two landslip areas.

We consider that there is likely to be a stress link between the two landslips and in addition, surface water and groundwater flows and conduits are likely to be linked. However, given the limited existing ground investigation data no substantial assessment can be made in this regard.

## 4.4 Slope Stability Modelling

The Lower Landslip area was modelled in 1989 and we have carried out preliminary model reviews as part of this assessment. The Lower Landslip area is shown on Figure 20 (appended).

A representative stability analysis was previously performed on one section through the landslide at the location of properties downhill of a low hazard part of the landslide, but where it was considered should failure occur, geological and hydrogeological conditions might be present which could result in total loss of the properties concerned and possible injury. No further analysis of the higher risk zones was undertaken.

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.

Stability analyses considered landslide deposits within the lower landslide subsystem, which extend to the valley floor. The potential for over-riding failures within the slope concerned was considered by the analyses of a range of potential failure surfaces. The deeper failure surfaces follow rockhead for most of their length along a presumed sheared layer caused by previous landsliding. Shallower failure surfaces and the basal part of the deeper surfaces are contained within previously un-sheared material.

Circular and non-circular failure surfaces were analysed using computer-based effective stress programs based on the methods of Bishop (1954) for circular failures and Janbu (1954) for non-circular failure surfaces. Deep failures within intact rock were not considered. The stability analyses demonstrated, a factor of safety above unity for 'over-riding' failures. The critical slip surface had lowest factors of safety of 1.4 (peak strength) and 1.1 (residual strength).

The assessments concluded that the slope was unlikely to suffer an 'over-riding' failure within the conditions which existed at that time. However, other failure modes, such as an 'engulfing' failure of the entire landslide may be more critical. These could trigger an over-riding failure. Steeper and less stable parts of the landslip system were not modelled, presumably due to low data resolution for those areas.

Preliminary model reviews as part of this assessment suggest similar factors of safety for the slopes modelled previously. It has been observed that the stability of the landslip is significantly influenced by the presence of groundwater. Where groundwater is assessed in closer proximity to ground level, factors of safety very close to unity are observed. Initial review suggests that stability and safety decreases northwards, away from Church Road and this correlates with historical events.

Further resolution on existing factors of safety at the various locations across Pantteg would be aided significantly by high resolution lidar survey data and iterative stability modelling. Modern methods of computer modelling and digital ground models would accelerate this process compared to techniques available in the 1980's and 1990's.

## 4.5 The Failure Model

Various types of landslip processes appear to have been active at the site. These include:

- Instability of a rotational nature, within the Llynfi Rock and underlying less competent strata;
- Fairly deep seated translational sliding (confined to the Godregraig area);
- Relatively shallow debris slides of the superficial deposits on the steep slopes;
- Debris flows associated with debris slides;
- Outbursts of groundwater from drainage conduits in soil/rock and mine entries, also associated with debris slides and debris flows;
- Rockfalls and rock slides.

In summary, the likely causes of the failure include:

- Collapse of rock from the Llynfi sandstone cliffs at the top of the slope and surcharge of the top of the slope.
- Naturally over-steepened slopes;
- Low strength superficial materials;
- Input/output from the mine drainage system;
- Collapse of old mine workings.
- However, instability is unlikely to be solely caused by collapse of old workings due to the historical rainfall link/evidence and it is more likely due to an interaction of collapse and preferential water flow (below);
- Preferential groundwater flows from the coal seams;
- Periods of heavy rainfall, which may be effected over time through climate change (surface water runoff and recharging groundwater);
- A link between groundwater in Lower Pinchin coal seam and rainfall has been tentatively established.
- However, little data on groundwater levels and interlink with landslide events is available. This should be a key piece of information to enable risk management;
- There is a possible groundwater conduit between Pantteg backscarp area and lower landslide area (Lower Pantteg) via possible mine tunnel.
- Blockages in this tunnel may enhance instability;
- 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;
- Trees in areas of instability may enhance movement and present a risk in themselves.

The relationship between historical events and instability has been explored in more detail in the following section.

## 4.6 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.

The timeline (see Section 2.3) has been utilised to review event frequency and typical large scale events to enable further consideration of the link between rainfall and instability, which is to be used in the risk assessment process. A visual timeline is presented as Figure 23 (appended).

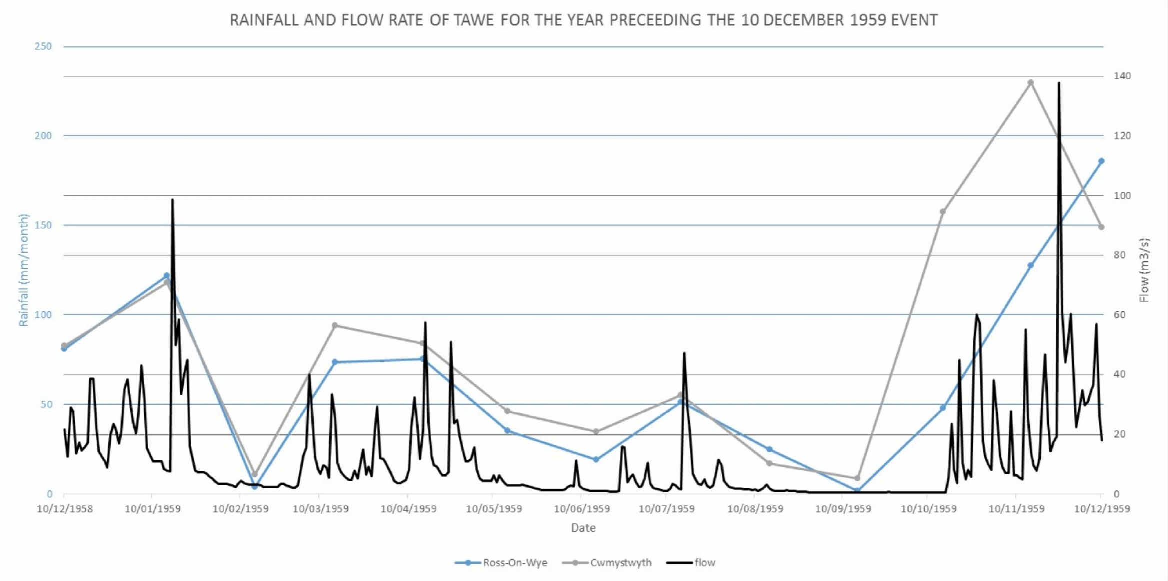
There is considerable variation in the available data at present and formal statistical analysis is required to provide confidence in the link between rainfall, river flow and periods of instability/events.

However, in an effort to explore the link between rainfall, river flow and instability, the following five major events have been selected to enable preliminary assessment of the relationship between rainfall, river flow and landslip events, namely the events that occurred in the following years: 1959, 1965, 1975, 1986 and 2012.

The following graphs present rainfall and river flow in the year preceding a major landslip event. The event coincides with the end of the period of time on each individual graph, as follows.

### 4.6.1 Rainfall and River Flow Data

The graph below shows rainfall from available gauges and river flow at Ystalyfera during the twelve months preceding the 19th December 1959 landslip.

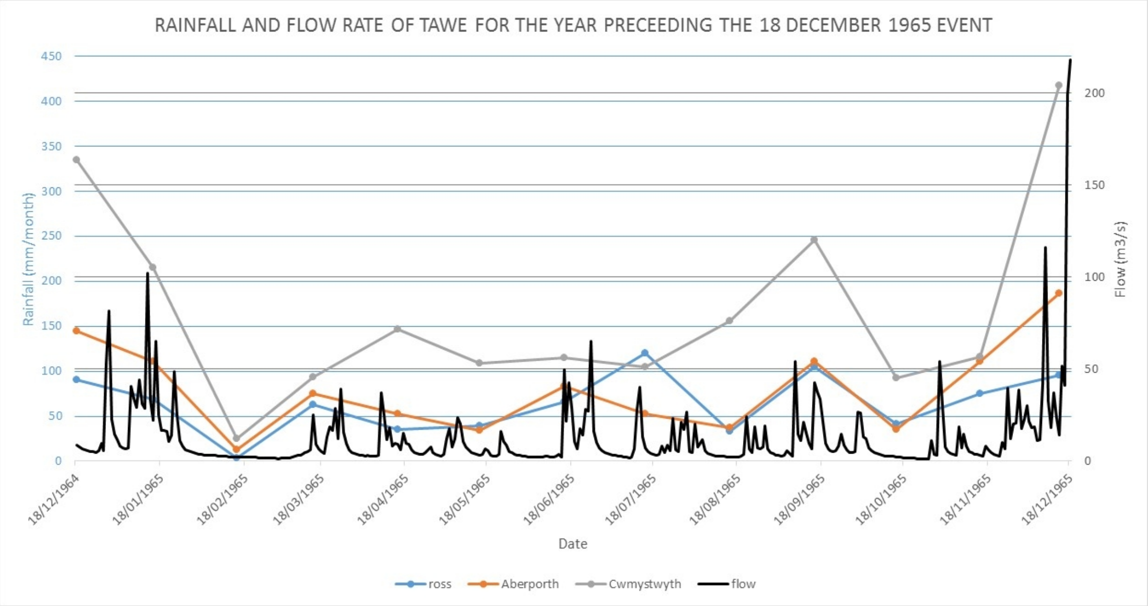


*Graph 2: Rainfall and Flow Rate for the year preceding the 10th December 1959 event*

Average annual rainfall appears low compared to the other selected events.

It can be seen that during the autumn period, rainfall increases steadily with a response seen in river flows. River flow exceeds 100m³/s prior to the landslip event.

The graph below shows rainfall from available gauges and river flow at Ystalyfera during the twelve months preceding the 18th December 1965 landslip.

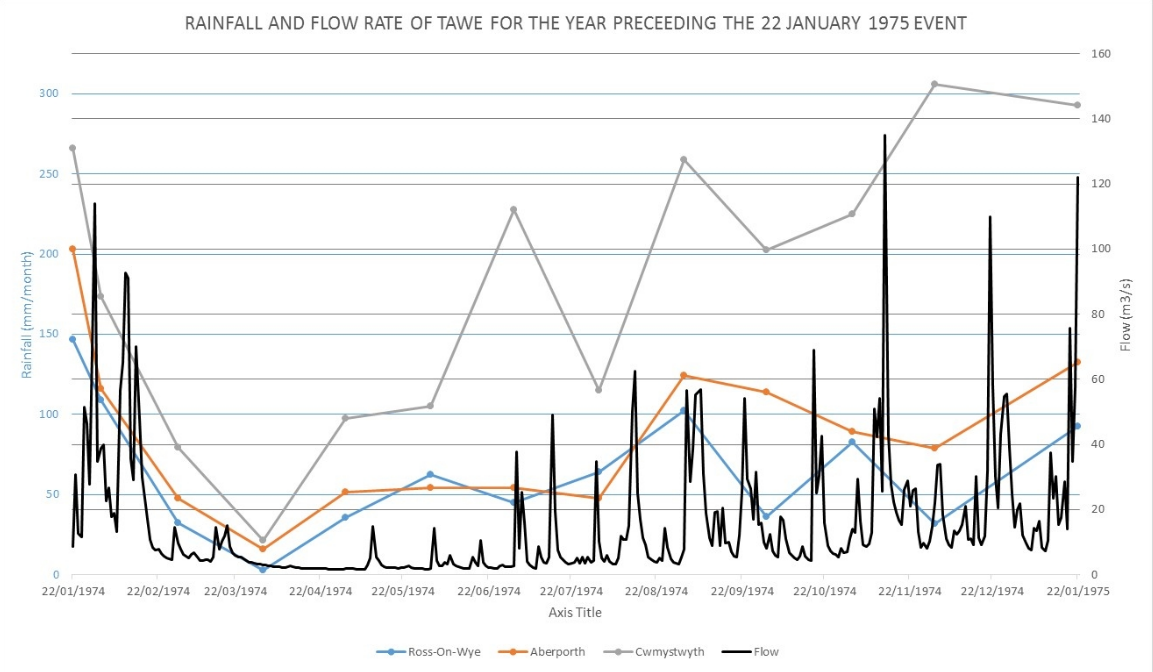


*Graph 3: Rainfall and Flow Rate for the year preceding the 18th December 1965 event*

Average annual rainfall appears moderate compared to the other selected events.

It can be seen that during the autumn period, rainfall decreases steadily. Rainfall increased notably during November and December 1965, with a response seen in river flows. River flow exceeds 100m³/s prior to the landslip event.

The graph below shows rainfall from available gauges and river flow at Ystalyfera during the twelve months preceding the 22nd January 1975 landslip.

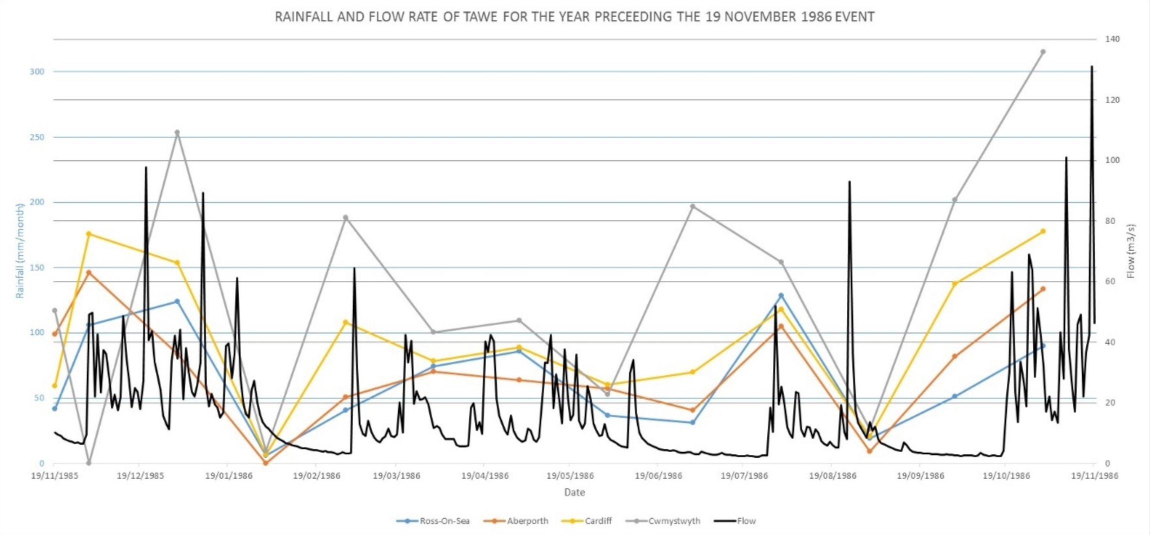


*Graph 4: Rainfall and Flow Rate for the year preceding the 22nd January 1975 event*

Average annual rainfall appears moderate compared to the other selected events. However, Cwmystwyth records notably higher rainfall. It can be seen that during the autumn period, rainfall increases steadily.

Rainfall increased notably during November and December 1965, with a response seen in river flows. River flow exceeds 100m³/s prior to the landslip event. 100m³/s river flow is also exceeded twice during November and December 1974.

The graph below shows rainfall from available gauges and river flow at Ystalyfera during the twelve months preceding the 19th November 1986 landslip.

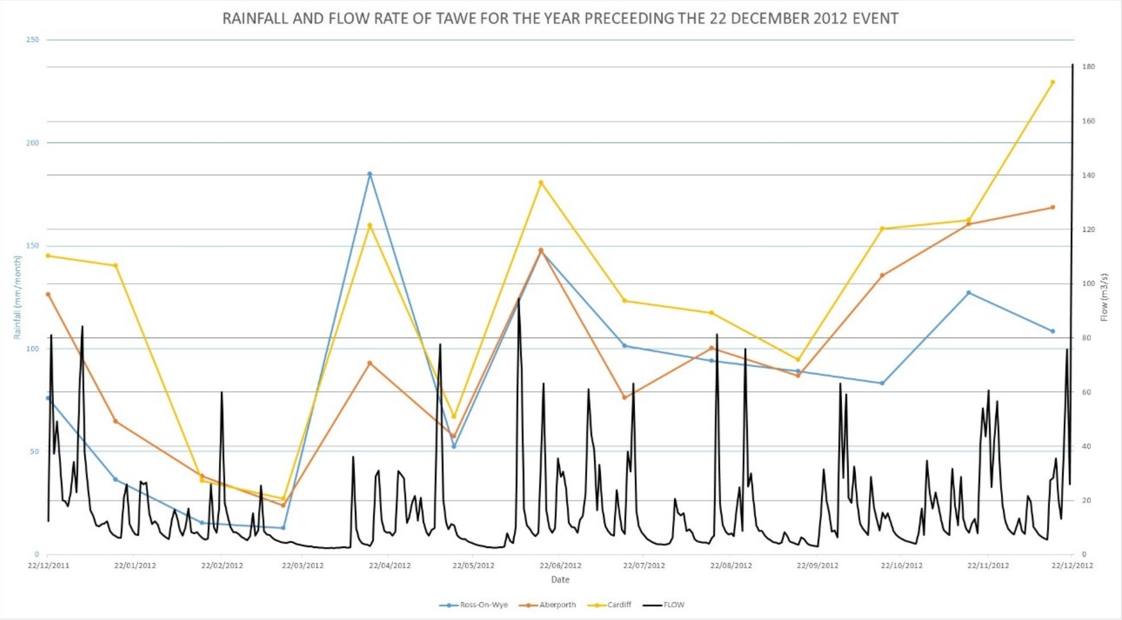


*Graph 5: Rainfall and Flow Rate for the year preceding the 19th November 1986 event*

Average annual rainfall appears higher compared to the other selected events. Cwmystwyth again records notably higher rainfall. It can be seen that following a drier August/September period, rainfall increases steadily through the autumn.

Rainfall increased notably during October and November 1986, with a response seen in river flows. River flow exceeded 100m³/s during the dry August/September and this may have been due to a very high intensity storm. River flow exceeded 100m³/s prior four times prior to the landslip event.

The graph below shows rainfall from available gauges and river flow at Ystalyfera during the twelve months preceding the 22nd December 2012 landslip.



*Graph 6: Rainfall and Flow Rate for the year preceding the 22nd December 2012 event*

Average annual rainfall appears higher compared to the other selected events. Cwmystwyth data has not been included. It can be seen that following a wetter summer period, rainfall increases steadily through the autumn.

Rainfall increased notably during October and November 2012, with a response seen in river flows. River flow exceeded 100m$^3$/s during approximately ten separate periods during 2012. From this data it may have been expected that a landslip would have occurred earlier in 2012, however there is likely complex relationship between rainfall, accumulation in the slope and subsequent instability.

### 4.6.2 Summary of Rainfall Data

Historical assessments have linked high rainfall to instability at Pantteg. From the preceding data shown graphically (Graphs 2 to 6), it is evident that many landslips occur in the period November to January (refer also to Table 1). In addition, the five major events selected are typified by wetter periods with coincident river flow above 100m$^3$/s prior to the landslip.

A major difficulty in assessing the frequency of the slope movement at Pantteg is that events may be hidden or imperceptible given the heavily vegetated nature of the slope and landslip (i.e. landslips may have occurred that have not been recorded). The suitability of geomorphological mapping is very dependent on consistency of the observer, seasonality and vegetation cover, therefore changes can occur without observation. We believe that a structured monitoring regime, perhaps using low altitude LiDAR surveys, would help address this fundamental difficulty. This is discussed further in Section 6.

There are significant uncertainties in using a river flows as a prediction of instability at present. However, provided the links between rainfall, river flow and instability can be investigated and monitored through time, a useful tool for managing the risks to life and property could be developed. This is discussed further in Section 6.

# 5 Hazard Identification and Risk Assessment

For the purposes of this current assessment, a hazard is a condition that can cause harm, e.g. boulder fall or debris flow. A risk is the probability, that any hazard will actually cause harm, e.g. to people or property.

Modern hazard and risk mapping undertaken in 1987 covered the wider landslip system and related the landslide hazards and risks to property and infrastructure locations and types. With the increased in confidence gained through the data acquisition from the 1989 ground investigation, further assessment was possible of:

- The geological profile;
- Ground model and landslide evolution;
- Groundwater levels.

As noted in Section 4, landslips at Pantteg and the wider system can be related to periods of heavy rainfall. The assessment was reviewed again in 1998 and an updated Hazard and Risk map was produced.

Following the landslip that took place on 22nd December 2012 in front of Pantteg Chapel, NPTCBC were advised on the immediate associated risks. Following this initial advice, the assessment was updated and the hazard and risk map was updated and presented in the Jacobs Engineering report (2013). For ease of reference the Hazard Zonation is presented in Figure 22 (appended).

Having reviewed the previous assessments, visited the site and discussed the landslip with NPTCBC, we are able to provide discussion on how assessment and management of the landslip can be taken forward.

## 5.1 Previous Approach

The previous landslide hazard assessments were carried out based upon the identifiable activity of the various landslide processes. The methodology was developed from established hazard and risk assessment processes for the Pantteg landslip and the wider landslip system. Previous studies divided the area into three landslide hazard zones, as described in Section 5.1.1.

### 5.1.1 Hazard Identification

The terms 'High', Medium' and 'Low' Hazard are qualitative only, related to the stability conditions within the landslip sites covered by these reports. It should also be noted that extreme frequency-magnitude events and external artificial influences may cause failures in areas currently classified as low hazard. The hazard identifications are described in Table 5a.

| Hazard Zone | Description |
|---|---|
| High | Area with active slope processes with relatively large displacements. High probability of continued movement within the lifetime of the property at risk. |
| Medium | Area with recent slope movement but largely inactive at present. Moderate probability of failure in response to abnormally large rainfall events within the lifetime of the property at risk. |
| Low | Area with no sign of recent activity and low probability of failure within the lifetime of the property at risk. |

*Table 5a: Landslide Hazard Zones as formulated in previous reports*

The framing of the hazard and risk, in terms of acceptability at Pantteg and beyond has been explored further and is discussed in Section 5.3.

### 5.1.2 Risk Assessment

Based upon the Hazard Zones, the various highways and structures within the area were divided into a number of risk categories. The original 1987 report had four divisions, although one of these was effectively 'uncertain – to be classified'; properties subjected to uncertainty were reclassified in 1989, and consequently only three designations have been used, as described in Table 5b.

| Hazard Zone | Description |
|---|---|
| 1 | Property or road within a high or medium hazard zone or within the likely trajectory of a landslide from such an area. Total loss of property likely and personal injuries are possible. |
| 2 | Property or road within a high or medium hazard zone or within the likely trajectory of a landslide from such an area. Due to reasons of location and/or topography the property is unlikely to suffer total loss and personal injuries are less likely. |
| 3 | Property or road within a low hazard area which is largely outside the direct effects of failures higher on the hillside in the present conditions. |

*Table 5b: Landslide Risk Categorisation as formulated in previous reports*

Jacobs confirmed that the 1989 map and the subsequent 1997 version classified only the risk to highways and properties, making no direct reference to statutory services, land quality or other receptors. The maps also identified buildings as uninhabited and consequently did not give them a risk rating. Some of these empty properties have been reoccupied.

## 5.2 2013 Assessment and Revision

The 2013 assessment continued the established method of classifying the Hazard and Risk at Pantteg. This was based on visual and desk study evidence only and no additional ground investigation was carried out.

Additional qualitative description of the reasons for categorisation were developed, been used, as described in Table 5c. A hazard zonation map is presented as Figure 22 (appended).

| Hazard Zone | Description | Reasons |
|---|---|---|
| 1 | Property or road within a high or medium hazard zone or within the likely trajectory of a landslide from such an area. Total loss of property likely and personal injuries is possible. | Presence of tension cracks and ground movements, evidence from distress (telegraph poles, fences, etc.). Also geological horizons with a recent history of instability. |
| 2 | Property or road within a high or medium hazard zone or within the likely trajectory of a landslide from such an area. Due to reasons of location and/or topography the property is unlikely to suffer total loss and personal injuries are less likely. | Areas that have exhibited instability within recent history, which may not have fully stabilised. |
| 3 | Property or road within a low hazard area which is largely outside the direct effects of failures higher on the hillside in the present conditions. | Area within the identified boundary of the landslips, with no visual evidence of recent movement. |

*Table 5c: Landslide Risk Categorisation as formulated in previous reports*

The classification is based upon visual evidence seen on site visits in 2013. Some evidence of instability may not have been apparent due to accessibility and vegetation growth. The main inspection was carried out following a prolonged dry period, so evidence of groundwater seepage may have been reduced.

An issue raised during the 2013 reclassification process was that previously unoccupied properties had become reoccupied and subsequently were not included in the hazard and risk map.

All geomorphological, hazard and risk assessment are to a degree subjective, so there is a need for continual review. The outline management plan discussed in following sections makes recommendations to address these issues and make the assessment process more quantitative and protective.

## 5.3 Update of Hazard Identification and Risk Assessment

Our assessment is likely to continue the established method of classifying the Hazard and Risk at Pantteg, once further information is available from ground investigation and monitoring. Historical assessment was based on visual and desk study and walkover evidence only and no additional ground investigation was carried out.

Observations during the autumn of 2015 conclude the landslip system is the same general condition encountered during 2013. However, there are some notable changes.

1. Tension cracks above the remediated would appear to have increased in size, however confirming this aspect is difficult without accurate time-spread topographical surveys, apart from recent observations.
2. At the crest of the remediated area, material appears to be falling and it is considered that 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 is likely to arrest the flow of some of this material.
3. It appears that previously unoccupied properties had become reoccupied. These were not included in the updated hazard and risk map.
4. There is bulging of the wall at the junction of Church Road and Graig Road. Saturated ground is prevalent and is flowing from the wall construction.

5. A mine tunnel has been identified on historical data and the tunnel entrance has been identified close to Clees Lane. This is a potential conduit for groundwater flow.

On the basis of the above, the existing Hazard and Risk map may not be justifiable at this point. We have used the above methods to aid this and further discussion is provided in the following sections. The hazard and risk zonation map has been updated to reflect the hazard zones only, this is due to the limited data present upon which to base a risk assessment and recent changes to the slope morphology. The plan is presented as Figure 22 (appended).

The above comments are based upon visual evidence seen on site visits in 2015. The main inspection was carried out following a relatively dry period, so evidence of groundwater seepage may have been reduced. All geomorphological, hazard and risk assessment are to a degree subjective, so there is a need for continual review. Some evidence of instability may not have been apparent due to accessibility and vegetation growth.

## 5.4 Preliminary Quantitative Analysis of Risk

We propose that the existing qualitative risk assessment be developed to aid understanding of actual and perceived risk presented by the landslip. This is an initial step in moving assessment of the landslip to quantitative methods.

In order to assess the risk presented at the site to humans and infrastructure, consideration of the frequency of historical events has been made. The level of risk has then been considered in a wider sense based on methods for assessing other geo-hazards.

The context in relation to annual likelihood of degrees of risk to life and property is outlined below.

| Degree of Risk | Annual Likelihood | | Risk |
|---|---|---|---|
| | To life | To property | |
| Very risky | 1 x $10^{-2}$ | 1 x $10^{-1}$ | Not Acceptable |
| Risky | 1 x $10^{-3}$ | 1 x $10^{-2}$ | |
| Some risk | 1 x $10^{-4}$ | 1 x $10^{-3}$ | Undesirable. Generally not tolerated by the public. |
| A slight chance | 1 x $10^{-5}$ | 1 x $10^{-4}$ | Concern. Tolerated by the public in special circumstances. |
| Unlikely | 1 x $10^{-6}$ | 1 x $10^{-5}$ | Generally acceptable. |
| Very unlikely | 1 x $10^{-7}$ | 1 x $10^{-6}$ | Generally acceptable. Of little or no concern. |
| Practically impossible | 1 x $10^{-8}$ | 1 x $10^{-7}$ | |

*Table 6: Relationship between Degree of Risk and Loss Events*

The area encompassed by the Pantteg and wider landslip system is approximately 54Ha. It is likely that more events have taken place within the area, however may not have been perceptible or created a negative effect in the locality.

From review of historical reports and the formulation of a timeline of landslip events (see Figure 23, appended), it can be seen that around 20 landslip events have occurred across the Pantteg and wider landslip system over the past 66 years. Using the strategy outlined by Cole (1987) for areas affected by abandoned coal mine workings;

- A critical, or significant, area of 200m$^2$ in plan has been considered. This would equate to a 'landslip' of 20m by 10m in plan. Smaller or larger landslip areas may or may not have an impact on life and infrastructure, however this is considered useful for preliminary quantitative assessment.
- The frequency of 20 incidences over 66 years within the Pantteg and wider landslip area has been utilised. It should be noted that it is likely that additional unobserved events have occurred during this time.

From the above, a future probability of $1.1 \times 10^{-4}$ per annum of landslip events occurring is estimated at Pantteg. This is the equivalent of 1 in 10,000.

Using the above framework for risk classification (but ignoring risk to money held in savings, held by banks etc.), the site would be classified as 'some risk' to life and a 'slight chance' of risk to property.

No incidents of loss of life have been recorded over time. However, we believe that this was only narrowly avoided on a number of occasions. Numerous incidents of loss of property have been recorded in Pantteg, most recently in 2012.

The Health and Safety Executive have adopted the following levels of risk, in terms of the probability of an individual dying in any one year:

- 1 in 1000 as the 'just about tolerable risk' for any substantial category of workers for any large part of a working life.
- 1 in 10,000 as the 'maximum tolerable risk' for members of the public from any single non-nuclear plant.
- 1 in 100,000 as the 'maximum tolerable risk' for members of the public from any new nuclear power station.
- 1 in 1,000,000 as the level of 'acceptable risk' at which no further improvements in safety need to be made.

We consider the overall risk to be of 'some risk' to life and property which is undesirable and generally not tolerated. In addition, large events at the site are unpredictable and have potentially serious consequences to life and property, which increases the sensitivity of the site.

Further consideration of the issues surrounding the nature of risk exposure at Pantteg should be made and may change the perceived risk considerably, i.e. is it voluntary or involuntary exposure. Public perceptions of voluntary or involuntary risk vary considerably.

The above risk assessment and derivation of there being an unacceptable risk to life and property has been used to consider what opportunities are present for ongoing management of the Pantteg Landslip in relation to a 'Hierarchy of Controls', as discussed in Section 6.

# 6 Risk Control Approach and Outline Management Plan

Previous assessments have concluded that the overall landslip system could not be economically stabilised and we concur with this opinion.

Considering the preceding discussion, a broad review of the site and options for managing risk is provided.

The outline management plan discussed herein makes recommendations to address these issues and make the assessment process more quantitative and protective. The subjective nature of the hazard and risk classifications and methods of improving this is discussed further.

## 6.1 Risk Control Approach

Various options have been considered in relation to a Hierarchy of Controls for risk management, as outlined below (from Management of Health and Safety at Work Regulations (MHSWR) 1999):

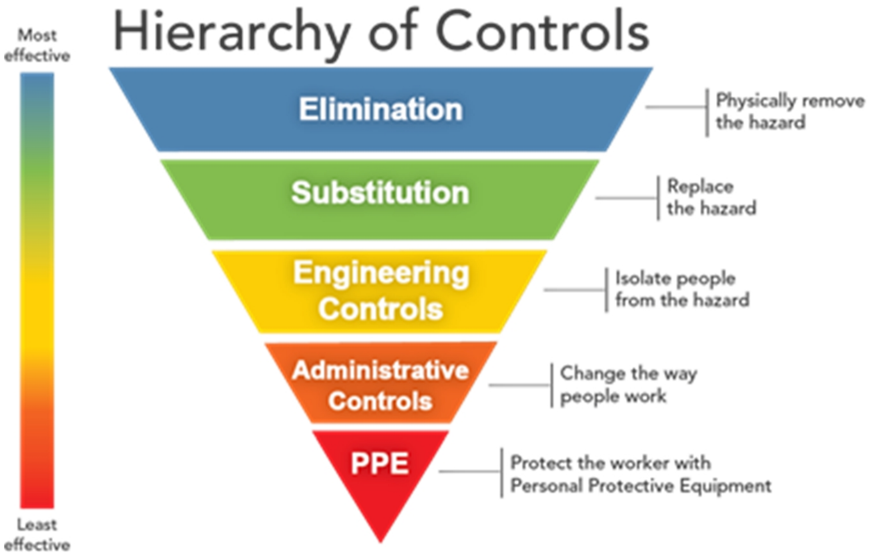


*Figure 14: Hierarchy of Controls*

Risks should be reduced to the lowest reasonably practicable level by taking preventative measures, in order of priority. Simply bypassing more effective methods to implement the easiest control measure is not preferable.

The risks presented by the historical stability issues can be managed, provided a clear and methodical strategy is generated and followed. In broad terms, the process of a risk management strategy for the Pantteg landslip is defined below:

- Physically removing the hazard is not possible (elimination).
- Replacing the hazard is not possible (substitution).
- Limited by feasibility and cost/benefit of stabilising the slopes (engineering controls).
- Changing the way people work, or behave, in reacting to potential landslips is possible (administrative controls).

- Personal Protective Equipment is unlikely to offer a feasible solution to the problems.

We understand that abandoning the private residences in Pantteg is not feasible. Previous assessments have concluded that the overall landslip system could not be economically stabilised and we concur with this opinion; this falls into the Engineering Controls category in the Hierarchy of Controls.

We consider that the next most preferable option is to enable a series of Administrative Controls for the Pantteg Landslip.

At the present time, and until new topographical, geomorphological and ground investigation/monitoring data becomes available, we consider that the existing Hazard and Risk zonation is not justifiable at this point and has been updated to present general hazard zones only (see Figure 22, appended).

To develop the existing geological and geomorphological assessments into a useful part of a management strategy for the site, we consider that all properties and infrastructure within the following defined areas be considered worthy of protection and inclusion in the management strategy/plan:

- High Hazard Zone
- Medium Hazard Zone

Further consideration of the merits of including properties within the Low Hazard zones will depend on future research/review and site information. This approach will aid assessment of the risk to empty properties that have more recently become occupied.

Administrative Controls for the Pantteg Landslip are likely to include a comprehensive and justifiable monitoring and warning system for residents. This will require investigation and research into the links between the ground, rainfall, river flow and movements/changes to the geomorphology of Pantteg, i.e. moving towards a more quantitative management approach.

## 6.2 Outline Management Plan

Assessment and management of the landslip can be taken forward through utilising the mainly qualitative methods of historical assessments and developing these towards a quantitative model for review, update and developing appropriate triggers and responses.

The following initial responsibilities are outlined:

- Earth Science Partnership to investigate, monitor, warn, comment and make proposals;
- NPTCBC to review public safety, arrange public forums, make provisions for input and make decisions following advice from ESP and other linked professionals, such as the NPTCBC Resilience Team of Emergency Planning Professionals.

Investigation, monitoring and regular survey aimed towards quantifying the links between rainfall, river flow and instability could enable river flow data to be used as a reliable early warning system for Pantteg. A tentative link between groundwater and high rainfall events has been established. However, there is little data on groundwater levels and interlink with landslide events. Refining this relationship is a key piece of information to enable risk management during periods of high rainfall (the critical periods).

A management plan is outlined below and takes in to account the findings of review and additional investigatory works reported herein. Key components that the Management Plan must include are as follows:

- Assessment of the condition and effectiveness of drains, conduits and streams. This includes the possible link between Mount Hill back-scarp area and lower landslide area (Lower Pantteg) via the possible mine tunnel.
- Refined and accurate surveys of the landslip to inform regular geomorphology assessment, especially following high rainfall events and periods of elevated groundwater.
- High resolution topographical data from LiDAR should be obtained will aid assessment of currently imperceptible drainage channels and future management of these to enhance stability.
- Appropriate resolution within the ground and slope stability models, relating to topography, geology, hydrology and hydrogeology. Regular LiDAR surveys may offer a high resolution in landform and could be a very useful tool in monitoring movements following high rainfall events.
- The creation of a ‘live’ risk register based on emerging conditions and findings.
- Establishing, if possible, the links between rainfall, river and groundwater and trigger values. Multi-faceted monitoring is likely to be required comprising:
    - Groundwater levels;
    - Rainfall and river flow;
    - Ground Movement: real time and spot monitoring via inclinometers and modern methods such as acoustic.
- 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.
- Using the various elements to create a formal Management Plan to enable reliable protection of human life, property and infrastructure (where possible).

The above can then be utilised to develop a suitable method of early warning system for residents using a similar approach to flood warnings in the area. A benefit of creating formal data links to river flow is that monitoring infrastructure is already in place (e.g. Natural Resources Wales flood alerts) that can be used to inform residents.

Future actions and objectives are set out in the following sections.

## 6.3 Management Objectives

With the absence of a feasible engineering remediation strategy for the site, the overarching aim is to create a suitable management system that enables decisions and reactions to emerging conditions and environmental factors.

Key ‘pillars’ of information are required to enable this approach:

- Rainfall and river flow;
- Ground model data;
- The reaction of the ground to events (movement data);

- Survey of landform.

The following flow diagram illustrates how confidence in the ground model can be gained by implementing the correct actions at the correct times. We envisage that through the short to medium term, significant confidence can be gained in the ground model that will enable the scale of monitoring and review to decrease over time until the point that simple and available datasets, i.e. rainfall and river flow in the Tawe can be used as triggers for two distinct pieces of public information:

1. Awareness of possible landslip occurrence, i.e. elevated risk;
2. Requirement for evacuation due to significant possibility of landslip occurrence, i.e. imminent danger.

Flow diagram showing likely actions within the Management Approach

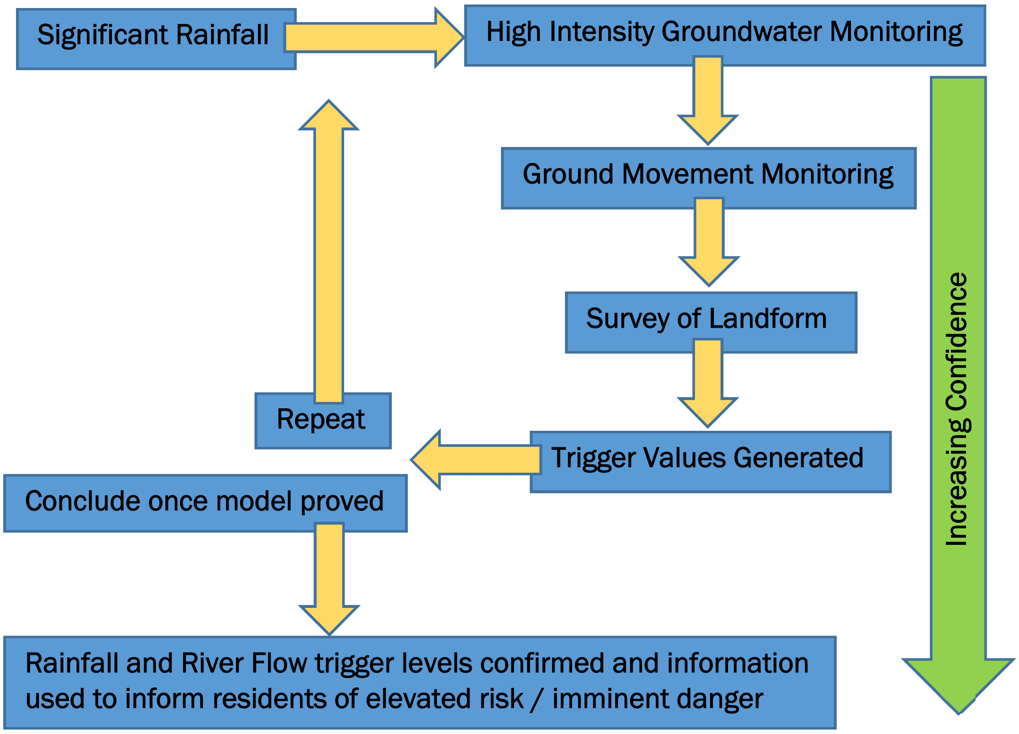


Figure 15: Flow diagram showing actions within the Management Approach.

River flow and rainfall data correlations would need to be statistically analysed for suitable confidence and reliability. In addition, a suitable rainfall gauge would need to be selected and correlated with historical data.

### 6.3.1 Short Term Management

The following actions and objectives are aimed at enhancing understanding of the links between rainfall, river and groundwater. Multi-faceted actions, investigation and monitoring is likely to be required comprising:

- Baseline surveys of topography and refined geomorphological mapping. Low altitude aerial LiDAR surveys will address the issue of access and vegetation cover and can achieve a three-dimensional resolution of 15mm to 20mm accuracy. Surveys are likely to be achievable of the whole Pantteg landslip within one day on site (plus data manipulation).

- Drainage survey/assessment, including the possible mine tunnel as a conduit (and area for simple improvement). Relatively simple physical improvements such as enhancing drainage should be commenced as early as possible for best value.
- Targeted investigation and monitoring of groundwater levels via boreholes, installation construction and instrumentation, especially during wetter periods and storm events.
- Rainfall and river flow observations.
- Ground Movement: real time and spot monitoring via inclinometers and modern methods such as acoustic.
- Initial assessment of the relationship between system inputs and reactions with preliminary quantification of possible trigger values.
- Assessment of ways to inform residents and public of periods of enhanced instability and likely ground movement.
- Enhance local drainage, e.g. the mine tunnel and local channels. Further locations for simple drainage improvements are likely to be highlighted by LiDAR survey.

### 6.3.2 Medium Term Management

We expect that following review of the initial actions, ongoing review will help establish the relationships with further confidence. Input is likely to require the following actions and objectives:

- Regular surveys of topography, including following ‘significant rainfall’ and refinement of geomorphological mapping.
- Continued monitoring of instrumentation, especially during wetter periods and storm events.
- Continued rainfall and river flow observations.
- Refined assessment of the relationships in the environmental system.
- Trials and refinement of utilising early warning systems for residents and the public.

### 6.3.3 Longer Term Management

We expect that once suitable confidence has been gained in the ground model and inputs/reactions, input will decrease significantly to ‘routine’ review, including:

- Regular surveys of topography and refinement of geomorphological mapping.
- Continued monitoring of instrumentation.
- Continued rainfall and river flow observations.
- Selection of data sources to inform long-term early warning systems for residents and the public (e.g. elevated risk / imminent danger).

## 6.4 Gap Analysis and Limitations

Through this study, a number of data gaps have been identified, where additional information would add to the knowledge surrounding factors affecting the stability of the Pantteg landslip.

From discussion with NPTCBC we understand that there is no anecdotal knowledge regarding the mine tunnel identified within the historical data. Geophysical assessment of the alignment of the tunnel could be undertaken along with clearance at the east portal identified during this study. The mine tunnel could present an important water conduit and could potentially be utilised in the future to enhance drainage of the landslip.

Contemporary topographical mapping and assessment of drainage during periods of moderate to high flow is needed.

Little information is available for visual assessments of new landslip features due to vegetation cover. Following contemporary topographical mapping (possibly via LiDAR), clearance could be implemented at selected locations.

We understand that correspondence following the 2012 landslip and the 2013 assessment report exists and review of this information would be useful.

Groundwater levels during storm events are of low resolution and this should be addressed as part of the management plan. Full statistical analysis of rainfall, river flow and landslip events has not been carried out and will provide useful for the management plan.

Further consideration of the justification of hazard levels to properties should be made, for example, specifically where adjacent properties have different historical risk ratings.

The assessments of stability hazard and associated risk included within this report are qualitative, based upon site observation in conjunction with interrogation of the available historic investigation and assessment data.

# 7 Conclusions

The instability at Pantteg is attributed to a number of interlinked factors. These factors exist across numerous similar landslips across South Wales within similar geological settings. 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;
- Human influences such as quarrying, coal mining and development. Recent failures appear to be generated in relation to the position of coal outcrops above Pantteg;
- Extended periods of heavy rainfall creating excess pore water pressures in soil and rock strata;
- Inputs and outputs from the mine drainage system and preferential groundwater flows from the coal seams.

From the preliminary quantitative risk assessment carried out, there is a perceived unacceptable risk to life and property presented by the landslip condition. We understand that abandoning the private residences and infrastructure in Pantteg is not feasible. Previous assessments have concluded that the overall landslip system could not be economically stabilised and we concur with this opinion.

At the crest of the remediated area (2013), material appears to be falling and it is considered that 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 is likely to arrest the flow of some of this material.

There is bulging of the wall at the junction of Church Road and Graig Road. Saturated ground is prevalent and is flowing from the wall construction. Focussed assessment and possible regrading in this area may reduce the risk of failure.

From the information reviewed, we consider that critical levels of rainfall and river flow are likely to exist and that when exceeded, landslips occur at Pantteg (and within the wider landslip system). It is clear that most of the landslip events occur during late autumn and winter months and development of baseline conditions within the landslip and relationship with rainfall will be critical to informing and developing a management approach.

There are significant uncertainties in using river flows as a prediction of instability at present. However, provided the links between rainfall, river flow and instability can be investigated and monitored through time, we consider a reliable trigger or threshold can be developed for the landslip 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 can be established to inform Pantteg residents about the risk of landslip activity (possibly within a day to week scale).

At the present time, and until new topographical, geomorphological and ground investigation/monitoring data becomes available, we consider that the existing Hazard and Risk map is not justifiable and investigation and assessment is required to refine this understanding. We recommend that properties within the historical High and Medium Hazard Zones and Category 1 and 2 properties/infrastructure be considered together in developing a management approach from the site. The approach is aimed towards moving from a qualitative assessment system to a quantitative one, whereby responses in the landform and reactions can be measured to enable better risk management into the future.

When developing the Management Plan, suitable consideration as to the methodology, the risk of ‘false alarms’ and uncertainties should be communicated to all relevant stakeholders, including local residents. This may be best achieved in a public forum and we have experience of similar events. The development of an early warning system will be an iterative process and the expectations of all parties should be managed from the outset.

# 8 Recommendations

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.

A number of actions and activities are required, as described in Section 6.2 and Section 6.3. Key recommendations to enable a reliable and effective Management Plan are as follows:

- Relatively simple physical improvements such as enhancing drainage should be commenced as early as possible for optimum effectiveness of subsequent actions.
- Assess the condition and effectiveness of drains, conduits, gullies and streams. This includes the possible link between Mount Hill back-scarp area and lower landslide area (Lower Pantteg) via the possible mine tunnel.
- Investigate and instrument key locations across the Pantteg landslip. Appropriate resolution within the ground and slope stability models, relating to topography, geology, hydrology and hydrogeology should be obtained.
- Establish the links between rainfall, river and groundwater and trigger values. Multi-faceted monitoring is likely to be required comprising, groundwater levels, rainfall, river flow and ground movement.
- Obtain high resolution topographical data from LiDAR. This will aid assessment of currently imperceptible drainage channels and future management of these to enhance stability. Regular LiDAR surveys may offer a high resolution in landform morphology and could be a very useful tool in monitoring movements following high rainfall events.
- Create a 'live' 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 create 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 above can then be utilised to develop a suitable method of early warning system for residents using a similar approach to flood warnings in the area. A benefit of creating formal data links to river flow is that monitoring infrastructure is already in place (e.g. Natural Resources Wales flood alerts) that can be used to inform residents.

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.

The ground investigation strategy and scope is discussed in the following sections.

# 9 Investigation Strategy & Scope

Since 2013, material has continued to fall from the crest of the remediated area. Evidence of movement has also been observed in other areas across the Pantteg landslip.

It is apparent that there is a link between rainfall events and movement/instability and the following sections outline physical investigation and assessment required to develop an understanding of these relationships. This will enable quantification of the ground model and the development of the management approach to the landslip hazards and risks.

A completed schedule of rates for the framework can be presented to NPTCBC as a separate document due to the commercially sensitive nature of the information.

## 9.1 Preliminary Investigation Strategy and Objectives

A summary of the key actions to enable a reliable and effective Landslip Management Plan, as highlighted in this report, are:

- Investigate and instrument key locations across the Pantteg landslip. Appropriate resolution within the ground and slope stability models, relating to topography, geology, hydrology and hydrogeology should be obtained.
- Establish links between rainfall, river and groundwater and trigger values. Multi-faceted monitoring is likely to be required comprising, groundwater levels, rainfall, river flow and ground movement.
- Obtain high resolution topographical data from LiDAR. This will aid assessment of currently imperceptible drainage channels and future management of these to enhance stability.

To progress towards the above, site investigation is required to increase resolution in the Ground Model and monitoring data at key currently accessible locations This is aimed towards achieving a balance of input and cost at this stage.

The physical possibilities of investigation are dictated by the site constraints. However, we consider there are enough discrete locations across the landslip area to enable the initial investigation and creation of discreet monitoring points. As part of this scoping assessment we have undertaken visits with drilling specialists to review access and to select suitable drilling rigs.

Instrumentation of boreholes, the installation of a rain gauge and obtaining access to river flow data has been considered. Discussions with specialist high resolution LiDAR surveyors have been undertaken and the recommendations are contained herein.

We understand that the investigation commission will be made under the standard terms of the South West Wales Framework to which we have been appointed by NPTCBC (implemented and managed by the, NPTCBC Corporate Procurement team). This framework includes a schedule of rates that have been market tested in terms of value (i.e. cost and quality considerations have assessed).

The recommendations in Section 8 of this report need to be discussed and agreed between ESP, NPTCBC and other stakeholders as not all actions are achievable within a single remit or role.

## 9.2 Proposed Investigation Strategy and Justification

In order to obtain key data to input into the geotechnical model it will be necessary to investigate and install instrumentation at notable points of the landslip, such as the top, middle and bottom of the landslip system. The aim of this is to provide information on the thickness of debris within the slide and to determine the groundwater profile across the system.

As the slip covers such a large area, several points will be required in the middle portion to determine variations likely to be present. The investigation will attempt to determine the types of landslip movements occurring, and if possible consider the presence and effects of deeper or larger rotational movement.

Due to the nature of the slip topography, geomorphology and current vegetation coverage, it will not be cost effective to access the whole area. Investigation positons have been chosen to balance areas that are accessible, within proximity to houses, i.e. in an area of high or medium hazard, and in locations that will provide usable information for the Ground Model.

Discussions with specialist aerial drone surveyors have been held and proposals obtained for a baseline Lidar survey of the Pantteg landslip to:

1. Provide a digital terrain model for review and identification of geomorphological features that are currently masked by vegetation.
2. Provide a digital terrain model that can be used within the management strategy to assess locations and magnitudes of ground movement following phases of instability over time.

This data will be correlated with the ground investigation findings to aid delineation of hazard zones.

The scope of the ground investigation has been developed considering the following relevant UK guidance and standards:

- BRITISH STANDARDS INSTITUTION (BSI). 2004. Eurocode 7: Geotechnical Design – Part 1: General Rules. BS EN 1997-1:2004, HMSO, London. (including UK National Annex).
- BRITISH STANDARDS INSTITUTION (BSI). 2007. Eurocode 7: Geotechnical Design – Part 2: Ground Investigation and Testing. BS EN 1997-2:2007, HMSO, London.
- BS5930:2015 Code of Practice for Site Investigations;
- BRITISH STANDARDS INSTITUTION (BSI). 1990. Methods of Test for Soils for Civil Engineering Purposes. BS1377, Parts 1 to 9, HMSO, London;
- BRITISH STANDARDS INSTITUTION (BSI). 2002. Geotechnical Investigation and Testing: Identification and Classification of Soil, Part 1. Identification and Description. BS EN ISO 14688-1. HMSO, London.
- BRITISH STANDARDS INSTITUTION (BSI). 2003. Geotechnical Investigation and Testing: Identification and Classification of Rock, Part 1. Identification and Description. BS EN ISO 14689-1. HMSO, London.

- BRITISH STANDARDS INSTITUTION (BSI). 2004. Geotechnical Investigation and Testing: Identification and Classification of Soil, Part 2. Principles for Classification. BS EN ISO 14688-2. HMSO, London.
- BRITISH STANDARDS INSTITUTION (BSI). 2006. Geotechnical Investigation and Testing – Sampling Methods and Groundwater Measurements. Part 1, Technical Principles for Execution. BS EN ISO 22475-1:2006. 2007 reprint. HMSO, London.

## 9.3 Ground Investigation Details

Due to significant access restraints across much of the landslip, it is proposed to utilise an excavator to clear vegetation and create safe access routes to the proposed borehole positions at the top of the landslip complex. This element is estimated to take around four to five days; a series of trial pits can also be implemented at this time to provide efficient investigation of the near surface materials. The locations of the trial pits are flexible and to be agreed on site. A schedule is presented in the following section and provisional locations are shown on the enclosed Figure 24. Trial pits will provide information on locations of shallow slips, descriptions of strata in-situ, excavatability, bulk samples for index testing and a potential for block sampling (if strata is conducive).

Following the creating of safe access routes, it is intended that a rotary drilling rig will be used to progress a series of boreholes to confirm the stratigraphy across the landslip and construct monitoring installations. Coring will be implemented within each borehole to enable the rock strata to be logged in detail.

The depth of each borehole has been estimated using previous information. However, the actual depths may vary considerably; this is due to the potential for thicker deposits of landslip material being located in other areas of the slip which cannot be accurately estimated and movement since historical investigations were implemented.

### 9.3.1 Permits and Licences

As the boreholes will be drilling into coal measures strata, a licence from the Coal Authority is required.

Some of the proposed borehole locations will be on or directly adjacent to the highway (e.g. at Graig y Merched). Approved contractors may be required to safely plan and excavate service pits within the highway and will also be responsible for final reinstatement, where necessary.

The requirements for traffic management will be confirmed with NPTCBC prior to the works and this will be dependent upon the final borehole locations. An allowance has been made in the costings for approved contractors to excavate and reinstate the borehole positions.

### 9.3.2 Laboratory Testing

A broad suite of geotechnical tests is to be carried out on soil and rock samples recovered during the investigation. This includes particle size distribution, atterberg limits and moisture content, plus various rock strength and index tests. The precise geotechnical testing schedules will be confirmed following the findings of the investigation and sample availability. A general budget has been provided as a separate document.

### 9.3.3 Proposed Borehole Installations

The aim of the proposed installations is to provide information over time on the groundwater level/pore water pressures and ground movements in response to precipitation. It is proposed to obtain this information through a series of monitoring devices across the site, as discussed further in following sections.

### 9.3.4 Instrumentation for Groundwater Monitoring

In order to determine the groundwater level and pore water pressures, vibrating wire piezometers will be installed. These measure positive and negative pore water pressures within fully or partially saturated soil or rock. Numerous piezometers can be installed in a single borehole, providing a pressure profile. They are suitable for long term monitoring and measurements can be taken on a set time frequency, of hourly or daily for example.

A major benefit of using vibrating wire piezometers is that an accurate time-series of groundwater data can be collected; this has a significant advantage over traditional spot monitoring which may miss peaks and troughs in the groundwater datasets.

Anticipated depths of installation are provided within the enclosed Table 7 (see Section 9.4). The final depth and number to be placed in each borehole will be determined as the work progresses as different ground or groundwater conditions may be encountered to those expected. A general budget has been provided as a separate document.

### 9.3.5 Instrumentation for Movement Monitoring

In order to provide information on the rate, direction and magnitude of movement, it is proposed to install inclinometers in selected boreholes. Fully automated inclinometers can be installed, however, these are generally very costly and a known slip surface or area of movement is needed prior to their installation. Due to the uncertainties of the ground model, it would not be recommended to put such costly equipment within the standpipes at this install stage. The inclinometers we propose to use require manual monitoring and thus the information they provide is obtained during site visits.

The daily or hourly information obtained by the vibrating wire piezometers and extensometers will be saved in a logger box at ground level which can then be downloaded and analyse at a future date. It is possible for this information to be automatically recorded and sent back to a receiving office. A general budget has been provided as a separate document.

## 9.4 Outline Borehole and Trial Pit Schedule

Figure 24 (appended), shows the proposed locations of boreholes and trial pits. Table 7 and Table 8 (below in Sections 9.4.1 and 9.4.2), present the proposed depths and justification for each location.

### 9.4.1 Borehole Schedule

| BH Name | Depth (m) | Geology | Terrace | Vibrating Wire Piezometer depth (m) | Inclinometer depth (m) | Comments |
|---|---|---|---|---|---|---|
| BH1 – Quarry | 60 | Sandstone over Lower Pinchin Seam (possibly others) | Upper | 5, 20, 40 | 60 | Borehole to confirm stratigraphy. Piezometer to be installed within the worked Pinchin Seam to assess groundwater. Inclinometer to assess if large scale rotational failure occurring to the rear of the currently identified backscarp of Pantteg Landslip area. Access will need to be made with an excavator. It may be possible to reduce the monitoring frequency following initial data review. |
| BH2 – GYM 1 | 30 | Colluvium over siltstones with Lower Welsh Seam | Middle | 5, 9, 20 | - | Borehole located in area of surface movement. Installations to provide information on movement and groundwater correlation within Colluvium and coal seams. Information on the shape of the landslip surface may be obtained in conjunction with other positions. Borehole position adjacent to roadway. |
| BH3 – GYM 2 | 35 | Colluvium over siltstones with Lower Welsh Seam | Middle | - | 35 | Borehole located in area of notable surface movement. Inclinometer and piezometer to provide information on movement and groundwater correlation within Colluvium and coal seams. Information on the shape of the landslip surface may be obtained in conjunction with other positions. Borehole position adjacent to roadway. Once likely zone of movement is confirmed, monitoring depths may be modified. |
| BH4 – Clees Lane | 15 | Colluvium over Siltstone, possible Lower Welsh Seam and Red Vein | Lower | 4, 8, 14 | - | Borehole located in an area of potential historic movement with notable solifluction lobes and mined strata. Piezometer to provide information on groundwater correlation within Colluvium and coal seams. Borehole position adjacent to roadway. |
| BH5 – Chapel | 25 | Colluvium over Siltstone, possible Lower Welsh Seam and Red Vein | Lower | 6, 10, 20 | 25 | Borehole located in area of notable surface movement. Installations to provide information on movement and groundwater correlation within Colluvium and coal seams. Borehole position adjacent to roadway. Once likely zone of movement is confirmed, monitoring depths may be modified. |
| BH6 – Church Road | 30 | Colluvium over Siltstone, possible Lower Welsh Seam and Red Vein | Lower | - | 30 | Borehole located in area of notable surface movement and near a drainage run. Inclinometer and piezometer to provide information on movement and groundwater correlation within Colluvium and coal seams. Borehole possibly within highway, requirement for highway management to be confirmed. Once likely zone of movement is confirmed, monitoring depths may be modified. |

*Table 7: Proposed Borehole and Installation Details*

### 9.4.2 Trial Pit Schedule

| BH Name | Depth (m) | Geology | Terrace | Comments |
|---|---|---|---|---|
| **TP1** | ~4m | Colluvium | Upper | Located within the quarry area to confirm shallow stratigraphy. |
| **TP2** | ~4m | Colluvium | Upper | Located within the quarry area to confirm shallow stratigraphy. |
| **TP3** | ~4m | Colluvium | Middle | Located along Graig y Merched to assess condition of soils in this zone. |
| **TP4** | ~4m | Colluvium | Lower | Located on Cyfyng Road to assess materials that comprise part of the ancient landslip. |
| **TP5** | ~4m | Colluvium | Middle | Located along Graig y Merched to assess condition of soils in this zone. |
| **TP6** | ~4m | Colluvium | Lower | Located on Clees Lane to assess materials that comprise part of the ancient landslip. |
| **TP7** | ~4m | Colluvium | Lower | Located on Clees Lane to assess materials that comprise part of the ancient landslip. |
| **TP8** | ~4m | Colluvium | Lower | Located along Church Road to assess materials in the recent landslip. |
| **TP9** | ~4m | Colluvium | Lower | Located along Church Road to assess materials in the recent landslip. |

*Table 8: Proposed Trial Pit Details*

## 9.5 Non-Intrusive Elements

### 9.5.1 Rainfall Data via Rain Gauge

We propose to install an automatic rain gauge at the site which will be able to measure daily rainfall to an accuracy of 0.2mm. The rainfall information can be stored in the rain gauge unit and this will enable comparison of the daily rain information, specific for the site, against groundwater and movement data, as discussed above. It may be possible to upgrade the rain gauge at a later date to include telemetry.

### 9.5.2 River Level Data

Natural Resources Wales (NRW) have been contacted to discuss the availability of river level data for the Tawe at two nearby locations, one is located just upstream and the other is located just own stream of the study site. NRW confirmed that this data will be free of charge. However, at present this is only available in monthly batches and currently no system for obtaining live data is available. NRW have confirmed that such a system may be possible to implement (this will require NPTCBC support and liaison).

### 9.5.3 LiDAR and GPS Survey

Whilst the proposed borehole installations will measure ground movement, and are key in determining the relationship between movement and groundwater levels, they will only measure movement at discreet points. In order to provide information across the entire landslip area, it is proposed to implement an aerial survey using Light Detection and Ranging (LiDAR) technology. Repeated surveys can be overlapped and interrogated and areas of ground movement can be identified.

As the unit is airborne, access to all areas of the site are possible. This technology does have limitations, it is only possible to carry out the survey in favourable weather conditions and very heavy vegetation can limit its effectiveness. The information that it will provide is however likely to be key in fully understanding geomorphology and where movement is occurring across the landslip.

We currently propose to undertake an initial survey as soon as possible, or at the same time as the borehole installations. Return visits are relatively costly and we therefore propose to review the effectiveness as further information is gathered, for example routine scans during the summer may not be required, and more frequent surveys may be more beneficial in the winter months.

A land ownership plan provided by NPTCBC (Ref: Land near Pantteg Chapel 15-0796) shows potential areas for take-off and landing for the survey unit. The exact location will be determined in due course.

In order to provide a reference for the borehole installations and LiDAR survey, it would be necessary to undertake a survey using a datum outside of the landslip area. This is to ensure that the information is not skewed by surface movements which may not be obvious to the human eye during repeat visits. We currently consider an initial survey, following installation of the boreholes is required. This will be reviewed following receipt of the LiDAR information.

## 9.6 Proposed Monitoring Regime

If the above options are adopted, hourly or daily groundwater pressures and movements will be logged, however, regular visits will be required to obtain the data from the loggers and monitor the inclinometers.

Some flexibility into the monitoring frequencies may prove beneficial, depending upon the results. For example, if little rainfall and/or movement is occurring in summer months, monitoring frequency could be reduced. However, if during wetter months' movement is increasing, then it may be prudent to increase the rate of monitoring visits. We recommend monitoring on a weekly or fortnightly basis initially and potentially after every heavy rainfall event. Such a programme will have to be flexible and reactive.

It is likely that several seasons of monitoring data is needed to gain a full understanding of the relationship between rainfall, groundwater and ground movement.

We initially propose to carry out the monitoring for a period of up to two years, or at least over two winter periods to provide the data needed to feed into the management plan, as described in Figure 15. An allowance for this has been made in the general budget provided as a separate document.

## 9.7 Reporting, Continued Assessment and Programme

Due to the difficult terrain and interactions of slope stability and heavy rainfall, it is recommended that the investigation be implemented outside of the winter period. Initial monitoring will be carried out on a fortnightly basis; after each visit, data processing, interpretation and assessment will be carried out. The information will be transposed into a live Management Plan document, in accordance with the data feedback and assessment structure discussed earlier in this report.

A completed schedule of rates, in accordance with the framework we are appointed under by NPTCBC, is presented under separate cover.

# 10 References

1. John Ball. Website accessed November 2015 (www.jlb2011.co.uk/walespic/).
2. British Geological Survey (BGS). 2013. Website accessed November 2015.
3. British Geological Survey (BGS). 1:10,000 Solid and Drift map: SN 70 NE.
4. British Geological Survey Directory of Mines and Quarries 2014.
5. The Coal Authority. 2015. Website accessed November 2015.
6. Cole, K. Building over abandoned shallow mines, a strategy for engineering decisions on treatment. Ground Engineering. May 1987.
7. Conway B W, Forster A, Northmore K J, and Barclay W J. 1980. South Wales Coalfield Landslip Survey. Institute of Geological Sciences, London.
8. EN 1997: Eurocode 7: Geotechnical design, 2004.
9. Godre'r Graig & Pantteg Landslides, Report on Hazard Mapping, report for the Lliw Valley Borough Council by Sir William Halcrow and Partners, July 1987.
10. Neath Port Talbot County Borough Council and the City & County of Swansea Joint Resilience Unit. Website accessed November 2015 (www.jointresilience.co.uk/default.aspx?page=9615).
11. Pantteg Landslide, Report on Ground Investigation, report for Lliw Valley Borough Council by Sir William Halcrow and Partners, December 1989.
12. Pantteg and Godre'r Graig Landslide Area, Report on Assessment of Landslide Hazard, Neath Port Talbot County Borough Council, February 1998.
13. Pantteg and Godre'r-Graig Landslips Slope Stability Review, Jacobs Engineering UK Limited, December 2013.
14. 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.
15. Rouse, 2000. In: Landslides and landslide management in South Wales. Wright, 2000. In: Landslides and landslide management in South Wales. National Museums and Galleries of Wales, Geological Series No.18. 2000. ISBN 0720004853.
16. Siddle, 2000. In: Landslides and landslide management in South Wales. Wright, 2000. In: Landslides and landslide management in South Wales. National Museums and Galleries of Wales, Geological Series No.18. 2000. ISBN 0720004853.
17. Strahan A. 1907. The Geology of the South Wales Coalfield, Part VIII, The Country around Swansea. Memoirs of the Geological Survey England and Wales, An Account of the Region Comprised in Sheet 247 of the Map. HMSO.
18. Wright, 2000. In: Landslides and landslide management in South Wales. National Museums and Galleries of Wales, Geological Series No.18. 2000. ISBN 0720004853