P03

# PEN-YR-ENGLYN LANDSLIDE RISK MANAGEMENT

## Drainage Strategy Report

**Project no. 4021526**

Prepared for:

Natural Resources Wales

June 2025

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# 1. Introduction

## 1.1 Purpose

The purpose of this document is to provide an overview of the proposed drainage design strategy and associated hydraulic modelling, including an overview of its evolution and development from the outline design produced by consultant Arup in the previous phase of the project (February 2023). This report also presents the proposed planning design, key associated decisions and modelling outputs.

## 1.2 Project Overview

The Ynysfeio colliery was founded in the 1850s in Pen-yr-englyn. As a result of mining operations, a coal tip was formed on the steep slopes above residential properties. The Pen-yr-englyn tip was part of Forestry Commission Wales' "Tips and Slips" programme. Alongside the rest of the programme, the planned stabilisation works were postponed in 2009. This was due to funding shortages following the 2008 financial crisis. The inferred coal tip boundary is shown on Figure 1-1. The plateau area shown also has a level of made ground formed of coal tip material.

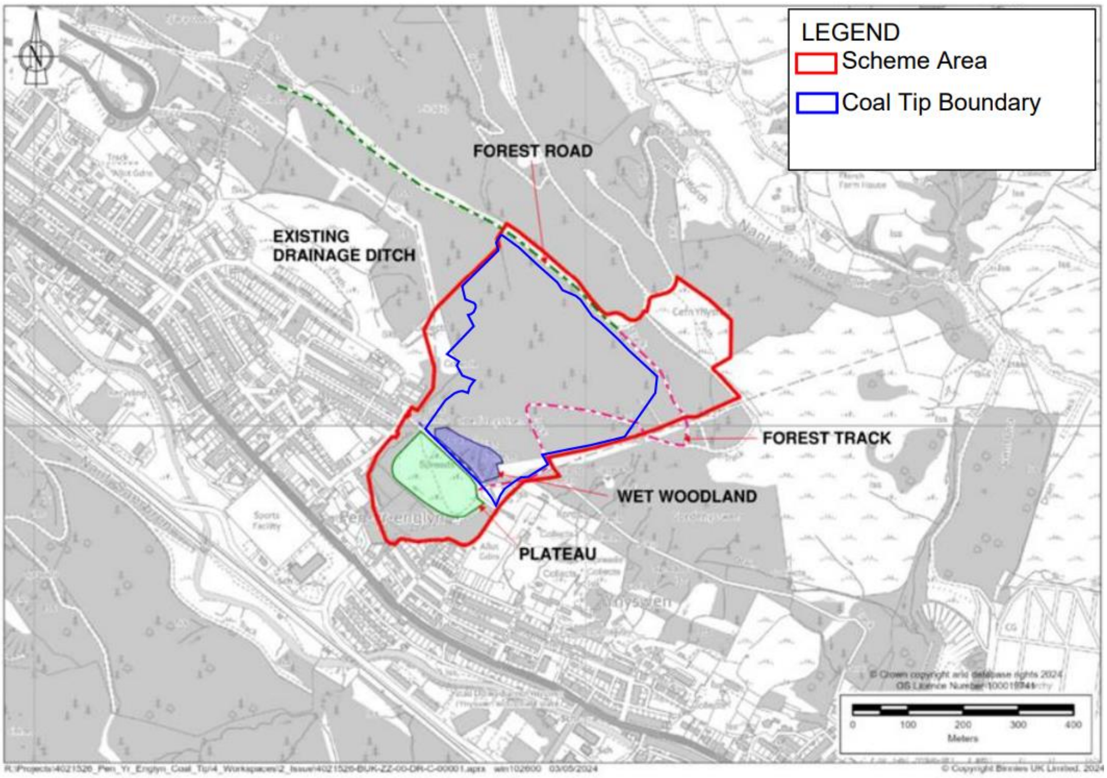



**Figure 1-1: Inferred Coal Tip Boundary**

## 1.3 Previous Phase

In recent years, following storm events such as Storm Dennis in February 2020, movement scars have exacerbated on the coal tip. As a result, Natural Resources Wales (NRW) commissioned consultants to assess the site and develop designs to manage the stability of the coal tip.

The outline design produced by Arup highlighted a preferred drainage layout, which has been the starting point for this drainage strategy approach.

## 1.4 Planning Policy

The drainage strategy presented within this report has been developed based on the principles of sustainable drainage systems (SuDS) in order to meet the Welsh Government Statutory Standards for Sustainable Drainage Systems and the requirements of the SuDS Approval Body (SAB) under Schedule 3 to the Flood and Water Management Act 2010.

The proposed drainage strategy has also been developed in alignment with the Rhondda Cynon Taf (RCT) Revised Local Development Plan 2022 – 2037 preferred strategy objectives which includes:

- Objective 1: Mitigate and adapt to the effects of climate change and reduce flood risk.
- Objective 4: Encourage healthy and safe lifestyles that promote well-being and improve overall health levels in RCT.
- Objective 8: Protect and enhance the quality and character of the landscape.
- Objective 9: Protect and enhance biodiversity.
- Objective 17: Address the impacts of the mining legacy in RCT.

## 1.5 Guidance and national, regional and local requirements

The proposed drainage strategy has been prepared in accordance with the relevant national, regional and local requirements and guidance:

- The SUDS Manual, CIRIA (2015)
- The Flood and Water Management Act (2010)
- The Environment (Wales) Act (2016)
- Planning Policy Wales (Edition 12)
- Technical Advice Note (TAN) 15: Development and Flood Risk (March 2025) issued by Welsh Government
- Welsh Government Guidance: Statutory Standards for Sustainable Drainage Systems - Designing, Constructing, Operating and Maintaining Surface Water Drainage Systems (2018)

## 1.6 Impact of climate change on the development

Climate change allowances issued by Welsh Government[1] provide the most current information on anticipated changes in rainfall resulting from climate change. The proposed drainage strategy outlined in this report has been developed using a 30% uplift to rainfall intensities to account for climate change. This allowance is considered appropriate for managing future flood risk at the site and represents a value midway between the central and upper estimates provided in the guidance, as shown in the table below. This approach has been adopted to ensure more robust management of climate change impacts, particularly given the sensitive nature of the coal tip.

**Table 1-1 Proposed Climate Change Allowances[2]**

| | **Total potential change anticipated for 2020s (2015-2039)** | **Total potential change anticipated for 2050s (2040-2069)** | **Total potential change anticipated for 2080s (2070-2115)** |
|---|---|---|---|
| **Upper estimate** | 10% | 20% | 40% |
| **Central estimate** | 5% | 10% | 20% |

1 Adapting to Climate Change: Guidance for Flood and Coastal Erosion Risk Management Authorities in Wales, August 2022

2 https://www.gov.wales/climate-change-allowances-and-flood-consequence-assessments

# 2. The Site Location and Baseline

## 2.1 Location

Pen-yr-englyn is a village situated between the communities of Treorchy and Treherbert in the Rhondda Fawr valley. The coal tip is situated on the north side of the valley above residential properties, an electricity substation and in proximity to a local primary school.

**Figure 2-1: Pen Yr Englyn Coal Tip**

## 2.2 Site Layout

The Pen-yr-englyn site consists of a forest road (formal forest access route) at its highest point, and a forest track (informal harvesting route) traversing down the site. Significant lengths of the track are currently unusable due to deep rutting. Sections of this tracks are also currently acting as informal drainage channels, and in some cases are channelling water towards the tip area.

The general site layout is shown in Figure 2-2 below.

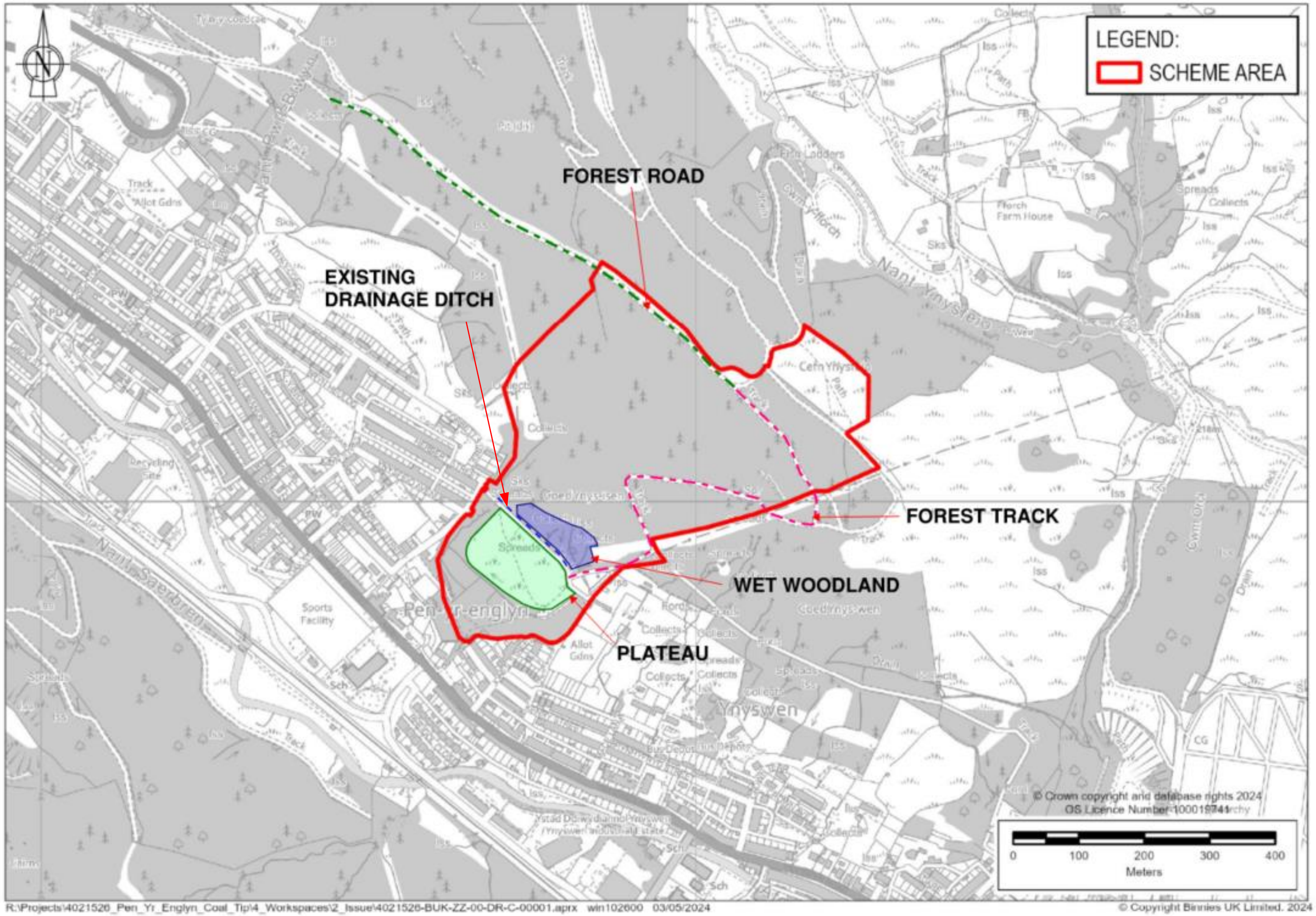



**Figure 2-2: General Site Layout**

**Figure 2-3: Forest track with timber harvesting 'goal posts'**

Below the forest road are steep slopes which were previously part of a conifer plantation but have recently been clear-felled. The site was clear-felled due to a statutory plant health notice to remove the Phytophthora ramorum diseased trees.

Within the former forested area, is a large bulge of tip material which is made ground from the mining spoil. Below the slopes and tip is a large plateau area which was part of previous remediation works to cap the shallow mine entries at the base of the hillside.

## 2.3 Site Topography and Area

The Pen-yr-englyn coal tip is characterised by steeply sloping topography (Appendix B) typical of former mining areas in the region, with a central section protruding out more than the slopes on either side. The site is situated on a steep incline, with gradients varying significantly (from 1:1 slopes on the main central tip area to shallower than 1:10), creating challenges for surface water management optioneering. The topography features uneven terrain, including ridges and depressions formed by historical tipping activities. Surface water flows often collect in localised low points, which can lead to ponding or erosion. This irregular landscape influences the hydrological behaviour of the site. This has been carefully considered within the drainage strategy to prevent surface water accumulation, reduce erosion risks, and mitigate slope instability in order to protect nearby properties and ecosystems.

## 2.4 Site Geology

Numerous phases of ground investigation have been undertaken on the site, from the 1980s to the present, including within the plateau area and upslope through the colliery tip and adjacent hillside. The thickness of colliery spoil is variable and up to approximately 20m thick at the deepest points, grading to shallower depths towards the edge of the tip. The colliery spoil is underlain by predominantly cohesive superficial deposits of Glacial Till (upslope) and Glaciofluvial Deposits (downslope). The thickness of the superficial deposits is also highly variable, but to a maximum depth of approximately 17m (but more typically around 8m) becoming thinner and in some places non-existent upslope as the topography becomes steeper. Bedrock underlies the superficial deposits and typically comprises mudstone and sandstone.

Groundwater has been encountered at various depths throughout the previous phases of investigation and depth below ground is largely dependent on the location of the exploratory hole in relation to the topography. Typically, slow groundwater seepages have been observed at the base of the colliery tip material, where it sits on top of the natural superficial deposits. Discrete observations of slow seepages or 'damp' spots have been noted within the colliery spoil, likely resulting from locally perched groundwater within more cohesive zones or due to migration of meteoric water. Groundwater (water table) level is typically within the underlying superficial deposits and bedrock. During the detailed design of the proposed drainage strategy, a conservative assumption will be taken in relation to ground water elements to negate risks associated with asset flotation.

The underlying soils within the site exhibit varying degrees of permeability. Four falling head permeability tests were undertaken on recompacted samples of colliery spoil. A range of permeabilities were recorded which is indicative of the variation in composition of the soils. A characteristic permeability value of 1x10-6 m/s is considered representative of the spoil overall. Two falling head permeability tests were also undertaken on Glacial Till samples indicating the deposit to be of low permeability; a characteristic permeability value of $1x10^{-7}$ m/s is considered to be representative.

## 2.5 Existing Watercourses and Drainage Arrangement

The forest road has an open channel drain next to it; this is in part impermeable concrete canvas with the remainder unlined. The concrete canvas has been recently repaired and is in good condition. There are some indications that the forest track had informal open ditch drainage with metal culverts passing flows underneath the track and back down the slope.

**Figure 2-4: Concrete canvas lined drain adjacent to forest road**

Between the plateau and the slope is an informal access track. This track has no formal drainage features, rather the surface allows water to travel across it from the coal tip to a wet wooded area directly above the plateau. Between this wet woodland area and the plateau is a drainage ditch the runs almost the entire width of the plateau.

At the east end is a culvert and trash screen that discharges water to the existing network (referred to as outfall location C). At the west end are two culverts that take the drainage ditch water back into the natural channel under the access (referred to as location A – a location selected to measure flows for design and modelling purposes and is not an outfall location at the site boundary). This eventually joins a culvert to the wider drainage network (referred to as outfall location B). There is also a drain that runs along the perimeter of the plateau. This drain connects to the western drainage channel, below the plateau. Both the east and west systems eventually outfall into the Afon Rhondda Fawr.

Figure 2-5 below presents observed surface water flow pathways and culvert locations and Figure 2-6 presents the existing sub-catchment areas.

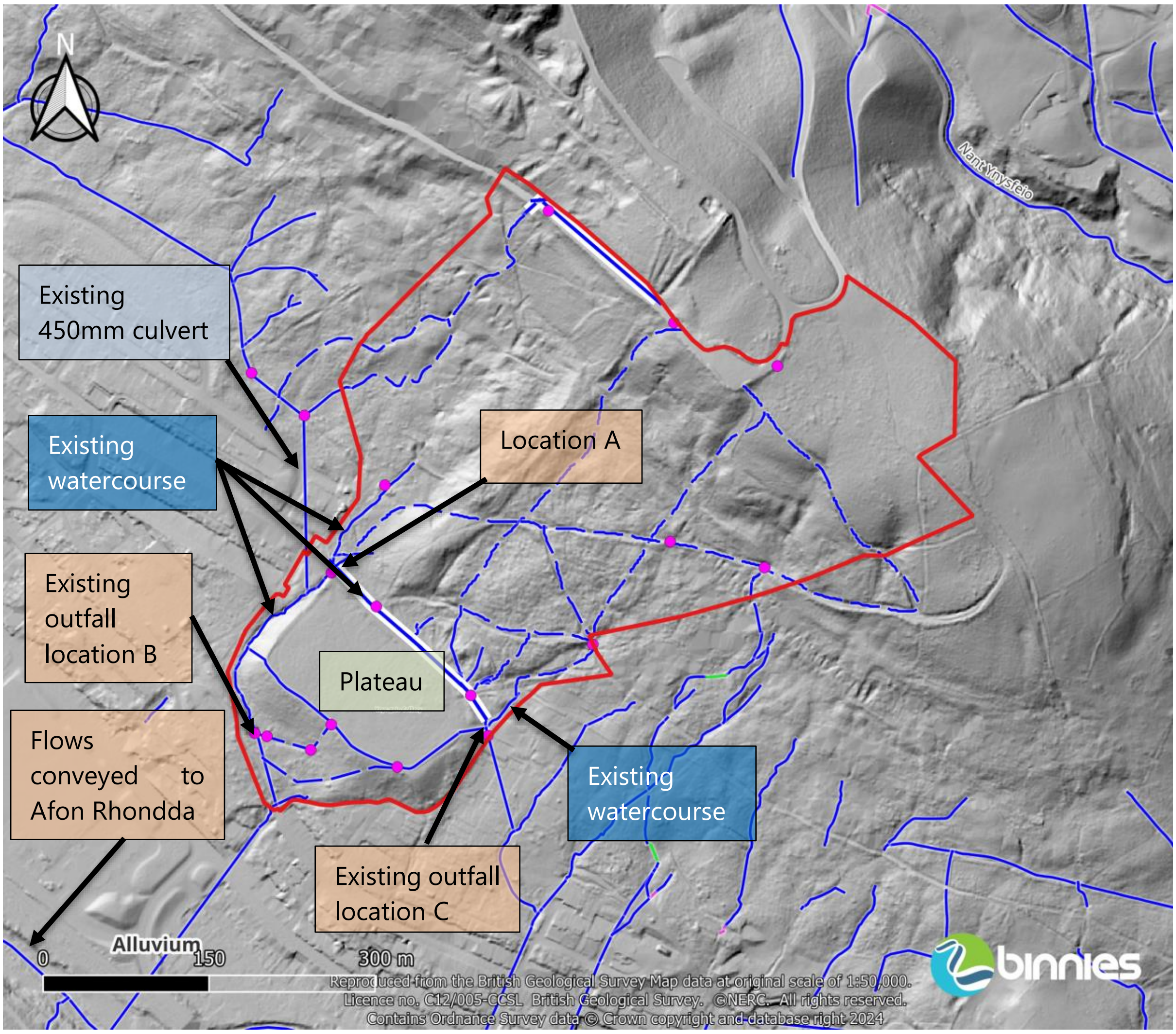



**Figure 2-5: Hydrology mapping including Binnies observed surface water flow pathways (blue-dashed) and culvert locations (pink)**

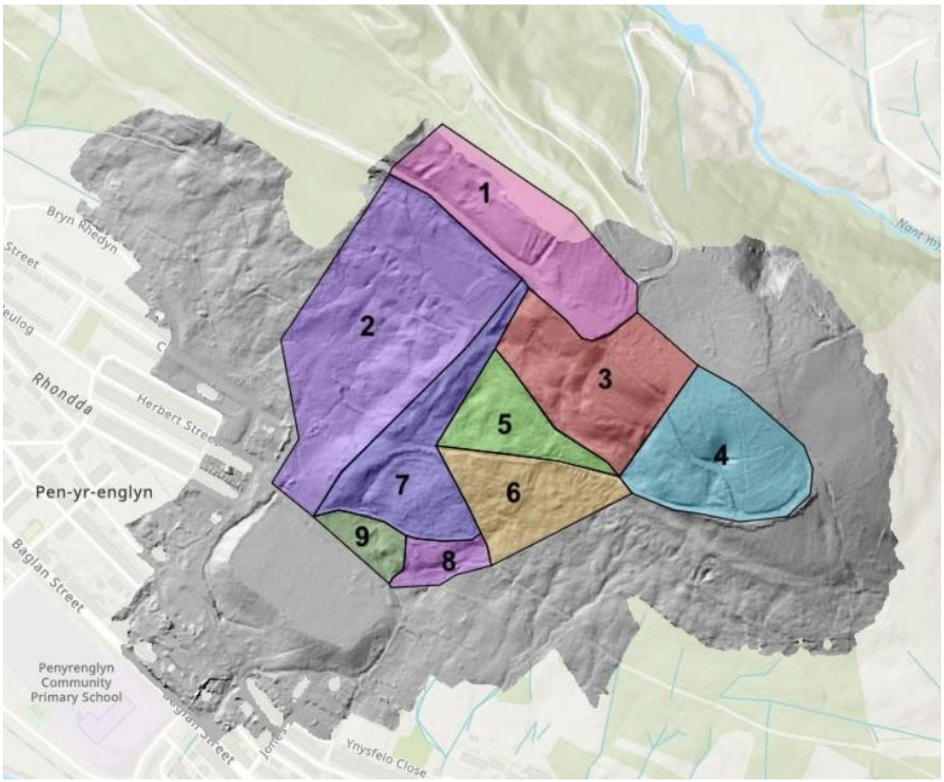



**Figure 2-6: Existing Pen-yr-englyn slope sub-catchment areas**

## 2.6 Hydrology & Hydraulic Modelling

IH 124 was issued in 1994 by the Institute of Hydrology. It extended the work of the Flood Studies Report (FSR) and aimed to provide a better estimate of peak runoff flow rates for small catchments than those previously available. The method is straightforward in its application and a correlation equation based on three parameters (SOIL, SAAR, and AREA), all of which are easily measurable or obtainable.

Subsequent to the publication of IH 124, the FEH and ReFH methods have been developed. Research undertaken by the Environment Agency's Science Project SC090031 explained that IH 124 underestimates QMED and has a higher mean error compared with the FEH Statistical method. Consequently, practitioners are currently advised to avoid using IH 124 on projects such as this. In addition to this, the IH 124 method does not directly account for the slope of an area when calculating the greenfield runoff rate.

Given the steepness of this site and the impact to existing runoff rates, the existing discharge rates for Pen-yr-englyn have been assessed more accurately by undertaking rainfall runoff modelling using a 2D ICM model off the existing site (see Table 2-1 for simulated existing surface water runoff rates for various storm events). For further detail on the baseline hydraulic model and a high-level schematic of the baseline model please refer to Appendix D.

An updated FEH22 design rainfall was used within the Infoworks ICM model, applied as direct rainfall onto the 2D model mesh. Different rainfall durations were used namely 30 min, 60 min, 90 min, 120 min, 180 min and 240 min. Return periods tested were the 1:30, 30+CC, 100 and 100+CC storm events.

It is important to note the following key assumption within the hydraulic model. As the proposal involves reducing overland flows across the surface of the tip and capturing and concentrating flows into the proposed surface water drainage infrastructure, a precautionary set of assumptions has been adopted. To accurately represent the existing scenario, an infiltration rate has been incorporated within the model. For the proposed drainage strategy model scenario, it has been assumed that the coal tip surface is impermeable. This conservative assumption ensures that the system contains additional capacity to store surface water flows and still remain compliant with existing discharge rates for the 1 in 100 year event + CC event. For further information regarding the hydraulic modelling undertaken, please refer to 5.Appendix D:.

**Table 2-1: Existing surface water runoff rates**

| Return Period | Location | Existing Flows (l/s) |
|---|---|---|
| **1:30** | A | 622 |
| | B | 893 |
| | C | 733 |
| **1:100** | A | 759 |
| | B | 1054 |
| | C | 887 |
| **1:30 + CC** | A | 782 |
| | B | 1088 |
| | C | 919 |
| **1:100 +CC** | A | 958 |
| | B | 1276 |
| | C | 1116 |

# 3. Proposed Drainage Strategy

## 3.1 Design Approach

The proposed drainage approach to manage surface water utilises natural processes and features present within the existing catchment. This entails strategically aligning water management approaches and techniques with the natural contours of the landscape, where water naturally flows. This also avoids transfer of water between catchments, which could contribute to increase flood risk to existing assets and downstream watercourses.

The strategy involves formalising and optimising the existing drainage channels and contours. This will enhance the resilience and effectiveness of the drainage system to carry water away from the coal tip whilst minimising environmental impact, visual impact and providing water quality benefits and environmental benefits. Implementing the proposed drainage channels (i.e. filter drains and ditches) will provide the added benefits of slowing runoff within the drainage assets, treating the runoff, increasing the time to concentration and providing a form of attenuation within the network.

To improve stability of the existing slope, geotechnical assessments have highlighted the requirement for subsurface drainage within the base of the lower central slope (within the permitter of the wet woodland area) and the base of the middle central slope. This will in turn reduce ground water levels which is beneficial for slope stability. For further information on the proposed sub-surface drainage arrangement, please refer to section 3.4 below.

## 3.2 SuDS Standards

The primary aim of the project is to stabilise the Pen-yr-englyn coal tip by managing water/ concentrating flows via SUDS assets as it flows over the tip. No impermeable areas will be created as part of the work, and surface water runoff is conveyed to the bottom of the slope where it discharges at existing outfall locations into existing surface watercourses. This report sub-section describes how the proposed drainage strategy meets the requirements within the Statutory standards for sustainable drainage systems[3].

Standard S1 of the Statutory standards for sustainable drainage systems states the following priorities with regards to surface water runoff discharge locations:

- Priority Level 1: Surface water runoff is collected for use;
- Priority Level 2: Surface water runoff is infiltrated to ground;
- Priority Level 3: Surface water runoff is discharged to a surface water body;
- Priority Level 4: Surface water runoff is discharged to a surface water sewer, highway drain, or another drainage system;
- Priority Level 5: Surface water runoff is discharged to a combined sewer.

Due to the nature of the works there is no use for collected water at the site. The scheme aims to limit infiltration to manage tip stability. Therefore, the majority of surface water runoff will be discharged to a surface water body (Priority Level 3). There will be some infiltration to the ground, however this will not be an increase on baseline infiltration at the site.

[3] Welsh Government Guidance: Statutory Standards for Sustainable Drainage Systems - Designing, Constructing, Operating and Maintaining Surface Water Drainage Systems (2018)

Standard S2 aims to manage surface water on the site, with a reduction in flows being discharged from the site. The scheme has been designed to reduce the run-off rate from the site for rainfall events across the following return periods: the 1 in 30 year plus climate change; 1 in 100 year plus climate change; and; 1 in 100 year (no climate change allowance). These flow reductions aim to mitigate any increased flood risk to people and property downstream of the site as a result of the development, and to protect the receiving water body from morphological damage. To support the reduction in runoff, an underground storage tank has been proposed to attenuate rainfall.

Standard S3 addresses requirements to minimise potential pollution risk by surface water runoff. The scheme incorporates grassed ditches (which trap suspended particles), filter drains (which through filtration, trap sediments and pollutants within porous media), and silt traps to improve water quality discharging to receiving water bodies. The proposed drainage strategy seeks to focus on natural treatment processes as much as possible in order to improve water quality.

Standard S4 aims to ensure the scheme maximises amenity benefits where possible. The scheme is to install positive drainage into slopes that were previously covered by a conifer plantation. The change from a dense, mono-culture plantation to a more diverse open habitat mosaic with a band of deciduous woodland retained at the slope toe will provide visual amenity benefit once habitats have matured. The hillside is already crossed by forest tracks, and the plateau by informal paths, that are accessible to and used by the local community. The drainage design retains this access and amenity use. Measures to reduce fire risk have been incorporated into the long-term management plan, comprising removing brash from a buffer zone either side of forest access tracks as part of drainage installation and then controlling vegetation growth in that buffer zone to maintain a fire break. This approach was agreed through consultation with the South Wales Fire Service.

Standard S5 seeks to maximise biodiversity benefits provided by the proposed drainage strategy. The management plan for the hillside is to allow natural regeneration to a habitat mosaic of predominantly grassland and scrub on coal spoil, a characteristic and important habitat of the Rhondda Valley, whilst controlling undesirable species such as conifer regrowth, providing biodiversity gain. The drainage scheme has been designed to fit into this context and uses existing topography where possible. Using blockstone cascades, gravel drains, drains topped with soils and vegetation, and stonework headwalls for horizontal drains will add diversity to the habitat mosaic.

The drainage design has taken the opportunity to connect into and improve existing watercourses. Dense canopies and vegetation along existing channels will be thinned out, and silt removed from drains, to open up the watercourses and provide biodiversity benefit as well as drainage. The project includes expanding the extent of existing wet deciduous woodland at the base of the slopes, and the drainage has been designed to allow some overland flow of water into this area where it will not affect slope stability.

Standard S6 seeks the design of robust surface water drainage systems so they can be easily and safely constructed, maintained and operated, taking account of the need to minimise negative impacts on the environment and natural resources. The drainage system designed for the Pen-yr-englyn coal tip includes blockstone cascades, filter drains, grassed ditches, and an underground storage tank, aimed at stabilising the tip and diverting surface water away from unstable areas. The design prioritises natural, low-maintenance solutions and where possible locates assets in areas with safe, easy access to facilitate construction and operation. Due to the steep gradient across the site, specialist access will be required for some construction and maintenance activities. Following review of a coal mining risk assessment produced by the Mining Remediation Authority, features have been positioned outside the zones of influence of mining hazards such as shafts and adits, with a watching brief planned during construction. The proposed system will be designed in accordance with applicable standards and best-practice to ensure structural integrity and long-term performance with minimal maintenance. A maintenance schedule has been included in Section 4 of this report to support ongoing management.

## 3.3 Proposed Sustainable Drainage System (SUDS) Assets

The proposed drainage layout drawing (4021526-BUK-ZZ-00-DR-C-00002) is presented within Appendix A. Existing surface water run-off rates from the coal tip are largely governed by its steep slope. The proposed drainage strategy utilises natural features and green drainage assets to manage runoff from the slope. Managing the water in a drainage network that diverts flows away from the main slopes reduces the risk of erosion, improving slope stability and reduces the amount of sediments and other fine material that would otherwise reach the receiving watercourses. This has additional benefits in terms of both improvements to water quality and reducing maintenance. The drainage strategy also utilises a storage tank to provide additional capacity within the system.

There are no proposed works to the forest road (located in the north of the site). The recently lined open channel north of the road directs water away from the slope. This channel outfalls south of the track in the north-west of the site. There is no provision of drainage infrastructure on the steepest slope at the top of the site (just below the forest road), as it is considered infeasible to construct on such steep gradients.

The existing topography generally conveys flows east and west of the main coal tip 'nose'. Two blockstone cascades have therefore been proposed at low points either side of main coal tip in order to intercept any surface water run-off that may find its way eventually to the main coal tip. An example blockstone cascade is shown in **Error! Reference source not found.**, below.

**Figure 3-1: A blockstone cascade local to Pen-yr-englyn**

An additional measure to divert surface water away from tip material entails provision of gravel-filled drainage channels in order to intercept flows and divert them to the blockstone cascade.

Downstream, it is proposed that filter drains will provide the dual function of track drainage and toe drainage for each of the slopes. They will convey flows towards the wet woodland at the bottom of the site and the existing watercourses located at the plateau.

The informal drainage channel caused by flows crossing the access track above the wet woodland will also be replaced with culverts in order to encourage positive drainage from the coal material and continue to direct water towards the wet woodland and sustain the habitat conditions in that area (Figure 3-2, below).

**Figure 3-2: Informal drainage channel flowing into wet woodland**

Table 3-1 below presents the benefits of the above-mentioned proposed SuDS assets.

**Table 3-1: Benefits of SuDS assets proposed at Pen-yr-englyn**

| SuDS Asset | Description | Environmental Benefits | Water Quality Benefits |
|---|---|---|---|
| Enhanced Filter Drains | A gravel filled trench with an impermeable base and vegetated top surface designed to manage surface water runoff and filter pollutants. A perforated pipe will be deployed at the base of the trench. | -Enhances biodiversity by providing habitat for flora and fauna.<br>- Improves landscape aesthetics and integrates with natural surroundings.<br>- Manages rapid surface runoff from steep slopes, reducing erosion risks and gully formations on coal tip and access tracks. | - Captures sediment that may carry pollutants from coal tip runoff.<br>- Reduces nutrient loading to downstream water bodies. |
| Gravel-Filled Trench | A rectangular trench filled with gravel, designed to collect and convey surface water. | - Protects against gully formation on coal tip slopes. | - Provides primary treatment by trapping sediment and pollutants (including hydrocarbons) in gravel voids from coal tip runoff. |

| | | | |
|---|---|---|---|
| Blockstone Cascade | A stepped feature constructed from natural quarried stones to dissipate energy in flows down steep gradients. | - Enhances landscape aesthetics and integrates with natural surroundings.<br>- Mitigates soil erosion and enhances slope stability, particularly effective for steep coal tips.<br>- Opportunity to create pools which also promote habitat diversity. | -Enhances oxygenation of water, promoting self-purification processes.<br>- Reduces pollutant loads by encouraging sediment settlement and microbial breakdown. |
| Grassed ditch | A shallow, grass-lined channel designed to convey and slow down surface water runoff. | - Provides habitat for grassland species and enhances landscape aesthetics.<br>- Reduces erosion risks by intercepting flows and stabilising soil on steep slopes. | - Traps sediment and associated pollutants from coal tip runoff.<br>- Slows flow velocity, allowing sediment and heavy metals to settle |
| **Storage tank** | A concrete structure with easy access for maintenance and cleaning. To be buried and sufficiently designed for vehicular loading. | - Buried with sufficient cover to allow priority habitat on the plateau to recover post works. | - Allows sediment deposition, reducing water turbidity. |

## 3.4 Proposed Subsurface Drainage

The proposed construction of the subsurface drains (as detailed in Appendix A) within the coal tip aims to reduce groundwater levels, improving slope stability by reducing pore water pressure in the soil. Elevated groundwater levels can reduce shear strength and increase the likelihood of slope failure, particularly at the Pen Yr Englyn coal tip, where the composition of materials is variable. The subsurface drain outlets will comprise natural stone headwalls in order to integrate with the local environment whilst providing robust protection and ensuring they can be located and inspected in the future. An example of a natural stone headwall is illustrated in Figure 3-3 below.

**Figure 3-3: Example sub-surface drain headwall.**

The subsurface drainage will exclusively drain the colliery spoil material located above the glacial till. Currently, seepage emerges from this spoil material at the base of the tip. This results in boggy conditions just above the 'plateau area', and thereby providing the necessary conditions to establish wet woodland habitat. To protect this habitat of principal importance, it is proposed that the subsurface drains located at the base of the Central Slope and to the north of the South Lower Central Slope will discharge flows into the wet woodland.

It has been estimated that less than a total of 5L/s from all subsurface drains will be sufficient to manage the groundwater to the desired levels for slope stability. Analysis has indicated that, provided the groundwater head within the colliery spoil remains below 5m, then slope stability should not be adversely affected. Based on the drainage layout provided in Appendix A, calculations indicate that a discharge rate of 0.003 L/s per drain, based on a spacing of 10m and drain diameter of 75mm, should be sufficient (refer to Appendix C for further explanation).

The response time of the subsurface drainage system is not expected to coincide with the peak of a storm, as runoff from storm peaks will occur almost immediately due to the steep gradient of the slope. Regarding the volume of water leaving the slope, it is proposed that flows from the Central Slope and South Lower Central Slope will be largely directed into the existing wet woodland areas. Given that the colliery spoil material currently exhibits groundwater seepage at the base of the slope, it has been determined that this approach will not introduce significant quantities of additional surface water volume to downstream networks.

For further information on the identified locations for the sub-surface drainage please refer to Appendix A.

## 3.5 Proposed Discharge Rates and Impermeable Areas

The proposed drainage design seeks to preserve the natural character of the area, maintaining its environmental assets. Conveyance of surface water flows are proposed through drainage assets rather than the coal tip material in order to improve slope stability.

An ICM model of the proposed network was developed and simulated for a range of storm events. Discharge rates have been assessed at locations B and C (Figure 2-6) to ensure there is no increase to discharge into the existing drainage network and associated outfalls for a 1 in 100-year rainfall event. The drainage strategy increases time to concentration where possible. This has been achieved through shallower gradients of filter trenches/ associated pipes and utilisation of forest track drainage at the east of the site. A storage tank has been included at the base of the slope to capture overflows, ensuring existing discharge rates are not exceeded following implementation of this strategy. The table below shows the discharge rates at location A (upstream of the storage tank) and outfall locations B and C at the site boundary.

As shown in Table 3-2, the drainage model predicts a small increase (<2.6%) in flow at location B during a 1 in 30-year event – highlighted in yellow. Given the reduction in all other return periods tested, it is proposed this minor uplift is accepted as the introduction of further flow controls to reduce run off would introduce increased risk of blockages to the system and likely an overall increase in storage required.

Please note Location A is upstream of the proposed storage tank and the increase in flows observed is mitigated due to the inclusion of this tank prior to outfall locations B & C at the site boundary.

**Table 3-2 Flows (l/s) at control points in the updated drainage network**

| Return Period | Location | Existing Flows (l/s) | With option (l/s) | Difference to existing (l/s) |
|---|---|---|---|---|
| **1:30** | A | 622 | 676 | +54 |
| | B | 893 | 916 | +23 |
| | C | 733 | 731 | -2 |
| **1:100** | A | 759 | 831 | +72 |
| | B | 1054 | 1041 | -13 |
| | C | 887 | 867 | -20 |
| **1:30 + CC** | A | 782 | 852 | +70 |
| | B | 1088 | 1069 | -19 |
| | C | 919 | 892 | -27 |
| **1:100 +CC** | A | 958 | 1082 | +124 |
| | B | 1276 | 1202 | -74 |
| | C | 1116 | 1038 | -78 |

# 4. Operation and Maintenance

Table 4-1 below presents the operation and maintenance plan for the proposed SuDS assets.

**Table 4-1: Proposed SuDS asset operation and maintenance plan**

| SuDS Asset | Maintenance Frequency | Maintenance Activities |
|---|---|---|
| **Gravel-Filled Trench (surface lateral drain)** | Quarterly | - Inspect for sediment build-up or blockages at inlets and outlets. |
| | Annually | - Remove accumulated debris and sediment from the surface. |
| | Every 5 years (or as required) | - Excavate and replace clogged gravel layers to restore permeability. |
| | After major storms | - Check for surface scour or clogging and address promptly. |
| **Blockstone Cascade** | Biannually | - Inspect for blockages, debris, or signs of erosion. |
| | Annually | - Check the stability of the stones and reset displaced blocks. |
| | After major storms | - Inspect for structural damage or excessive sediment accumulation and clear as necessary. |
| **Filter Drain** | Biannually | - Inspect for blockages, overgrown vegetation, or sediment build-up at inlets and outlets. |

| | | |
|---|---|---|
| | Annually | - Remove sediment and debris from the filter material. |
| | Every 5 years (or as required) | - Replace or refurbish filter media to maintain performance. |
| **Grassed Ditch** | Biannually | - Inspect for erosion, debris, and overgrown vegetation.<br>- Cut grass to prevent overgrowth and ensure consistent flow. |
| | After major storms | - Check for and repair gully formation, sediment build-up, or damaged vegetation. |
| **Subsurface drains** | Biannually | - Inspect for blockages, debris, and overgrown vegetation. |
| | After major storms | -Inspect for any damage or blockages |
| **Silt traps** | Annually | -Clear silt from all catchpits and check chamber to ensure there is no damage |
| | After major storms | -Clear silt from all catchpits and check chamber to ensure there is no damage |
| **Storage Tank** | Quarterly | -Inspect pre-treatment structures (silt trap), inlets and outlets for blockages |
| | Annually | -Inspect all inlets, outlets, vents and overflows to ensure that they are in good condition and operating as designed |
| | Every 5 years (or as required) | - Inspect for excessive sediment accumulation and clear as necessary |
| | After major storms | - Inspect for excessive sediment accumulation and clear as necessary. |

# 5. Conclusion

The proposed surface water drainage strategy for stabilising the Pen-yr-englyn coal tip presents a comprehensive and environmentally sensitive solution to mitigate risks to people and properties downstream of the slope. By integrating SuDS solutions and targeted subsurface drainage, the strategy manages surface water runoff whilst ensuring no detriment to the environment. Hydraulic modelling demonstrates the strategy overall, reduces runoff rates by increasing the time to concentration and utilising overflow storage.

Subsurface drainage deployed at the slope's base will discharge flows into the wet woodland (a habitat of primary importance) in order to ensure that the strategy does not cause detriment to this habitat.

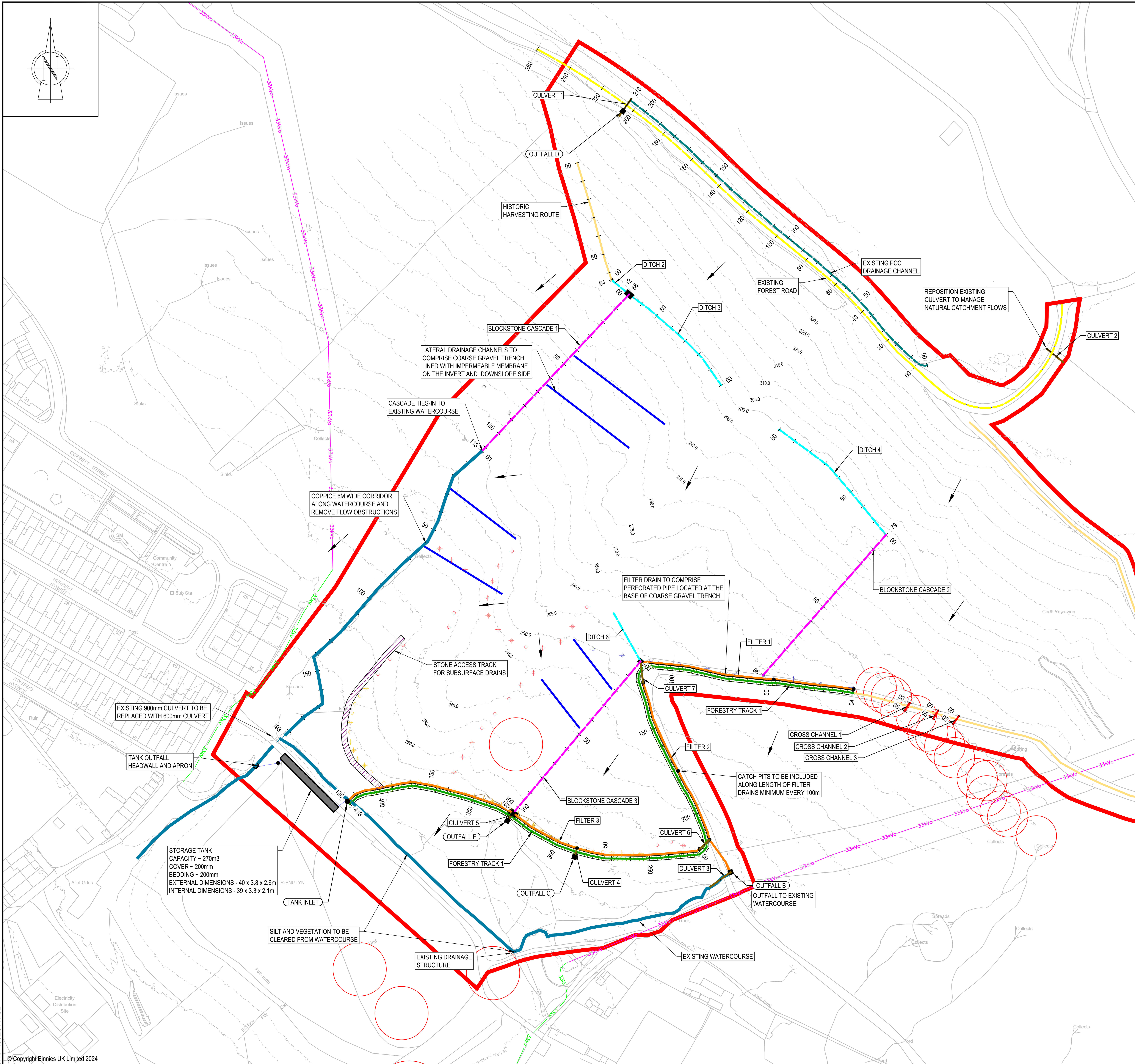
This proposed drainage strategy not only improves the stability of the coal tip but also prioritises the safety of downstream communities and properties while contributing positively to the surrounding environment.

# APPENDICES

## Appendix A: Proposed Drainage Layout and Details

4021526-BUK-ZZ-00-DR-C-00010

4021526-BUK-ZZ-00-DR-C-00011




SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION:

IN ADDITION TO THE HAZARDS OR RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, THE FOLLOWING SIGNIFICANT RESIDUAL RISKS SHOULD BE NOTED. FURTHER DETAILS ARE INCLUDED IN THE CDM DESIGN RISK MANAGEMENT REGISTER

CONSTRUCTION:
TBC

MAINTENANCE, CLEANING AND OPERATION:
TBC

DECOMMISSIONING OR DEMOLITION:
TBC

Note: The limits, including the height and depths of the Works, shown in this drawing are not to be taken as limiting the obligations of the contractor under Contract.

NOTES:
1. ALL DIMENSIONS IN METRES AND ALL LEVELS IN METRES AOD, UNLESS NOTED OTHERWISE.
2. REMOVE LOOSE BRASH AND DEBRIS FROM WORKING AREAS.
3. OUTFALLS C AND E ARE TO PRESERVE WET WOODLAND HABITAT.
4. ATTENUATION OF SURFACE WATER FLOWS WILL BE PROVIDED WITHIN A COMBINATION OF PROPOSED CHANNELS, PIPES, COURSE GRAVELS WITHIN FILTER/ GRAVEL TRENCHES AND STORAGE TANK AT THE BASE OF THE SLOPE.
5. IMPERMEABLE AREAS WILL NOT INCREASE AS A RESULT OF THIS DESIGN.
6. DISCHARGE OF OUTFALL FLOWS INTO THE EXISTING ORDINARY WATERCOURSE ARE SUBJECT TO OWC AGREEMENT WITH THE LLFA.
7. ALL PROPOSED DRAINAGE INFORMATION IS SHOWN INDICATIVELY.
8. UTILITIES INFORMATION PROVIDED ON DRAWING 280018-ARP-XX-00-M2-CW-0002.
9. KEY UTILITIES PRESENT WITHIN THE SITE ARE SHOWN INDICATIVELY ON THIS GA.
10. TRACK SIDE DRAINAGE (FILTER DRAIN)
ESTIMATED MANHOLE DIAMETERS 1.5-2.1M
ESTIMATED PIPE COVER LEVELS 0.6-2M
ESTIMATED PIPE DIAMETER 0.6M

LEGEND
- SUB-SURFACE DRAIN LOCATIONS AT 5M SPACING
- SUB-SURFACE DRAIN LOCATIONS AT 10M SPACING
- SUB-SURFACE DRAIN LOCATIONS AT 15M SPACING
- SUB-SURFACE DRAIN LOCATIONS AT 20M SPACING
- APPLICATION BOUNDARY
- IMPERMEABLE DITCH ALIGNMENT (DETAIL C)
- PCC DRAINAGE CHANNEL ALIGNMENT
- FILTER DRAIN ALIGNMENT (DETAIL A)
- CASCADE DRAINAGE ALIGNMENT (DETAIL B & F)
- CULVERT DRAINAGE
- CROSS CHANNEL DRAINAGE (DETAIL E)
- LATERAL DRAINAGE (DETAIL D)
- INDICATIVE SILT TRAP
- INDICATIVE CATCH PIT
- INDICATIVE OUTFALL
- FOREST TRACK AREA FOR IMPROVEMENT (1030m²)
- STONE ACCESS TRACK FOR SUBSURFACE DRAINS
- EXISTING FOREST ROAD ALIGNMENT
- FORESTRY TRACK ALIGNMENT (FOR IMPROVEMENT)
- EXISTING FOREST TRACK
- EXISTING WATERCOURSE
- EXISTING GENERAL SLOPE INDICATOR
- MINE ENTRY EXCLUSION ZONE

UTILITIES
- 33kV — ELECTRIC - 33kV
- 33kVo — ELECTRIC - 33kV (OVERHEAD)

10m 0m 10m 20m 30m 40m 50m 60m 70m
Scale 1:1000

| Rev | Drawn | Chkd | Rvwd | Apprvd | Date | Description |
|---|---|---|---|---|---|---|
| P01 | CF | SP | AH | AH | 26/09/24 | FOR INFORMATION |
| P02 | CF | SP | AH | AH | 09/05/25 | FOR INFORMATION |
| P03 | CF | SP | AH | AH | 15/05/25 | 0 |
| P04 | RC | AA | AH | AH | 09/07/25 | FOR INFORMATION 0 0 |
| P05 | RC | AA | AH | AH | 22/08/25 | FOR INFORMATION |

Designed by: Date:

Status
S3 Suitable for Review and Comment

Client
Cyfoeth Naturiol Cymru
Natural Resources Wales

Client Project No. Revision

binnies
Binnies UK Limited
Spring Lodge, 172 Chester Road, Helsby, Cheshire, WA6 0AR, UK.
Tel: +44(0)1737 774155

Project
PEN-YR-ENGLYN OPT C TCS

Drawing title
GENERAL ARRANGEMENT

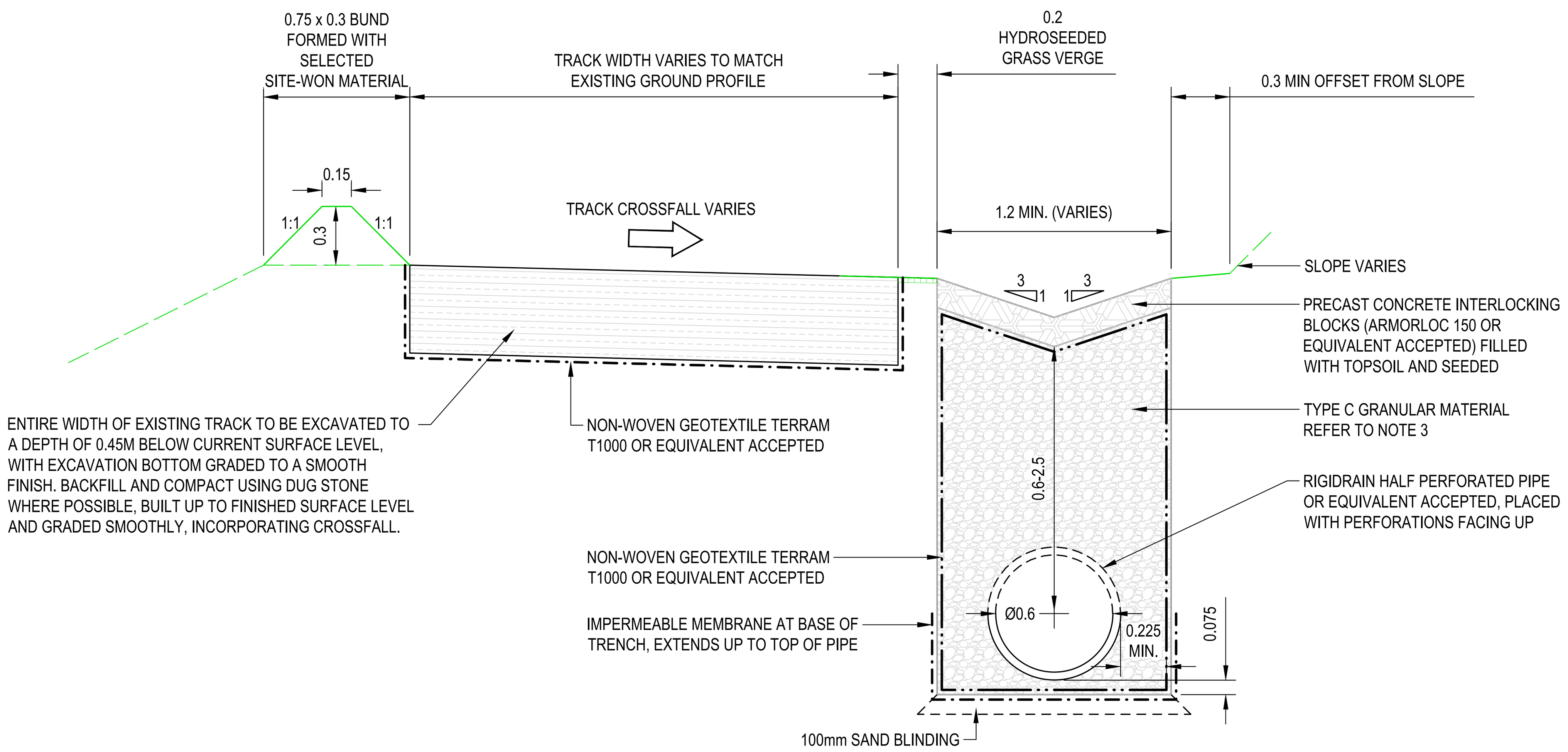
Drawing scale: 1:1000 Sheet size: A1

Drawing no. 4021526-BUK-ZZ-00-DR-C-00010 Revision P05

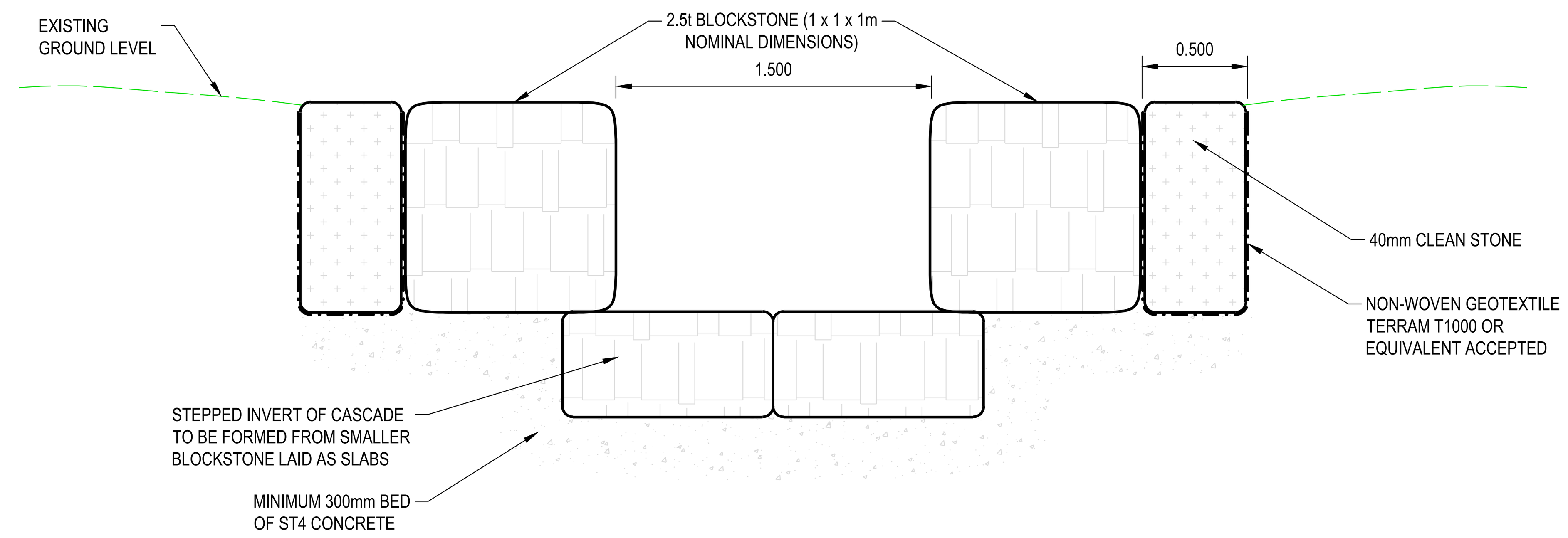
Parent Model: SHEET NAME

Note: The limits, including the height and depths of the Works, shown in this drawing are not to be taken as limiting the obligations of the contractor under Contract.

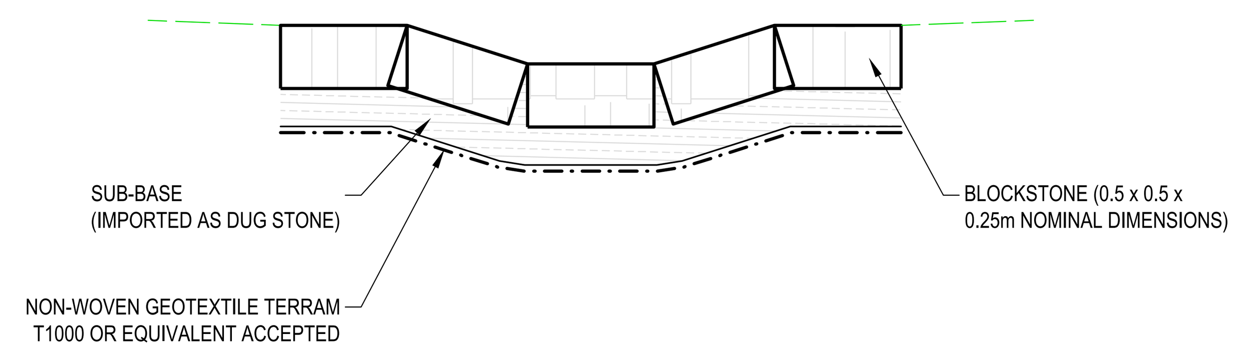
NOTES:
1. ALL DIMENSIONS IN METRES AND ALL LEVELS IN METRES AOD, UNLESS NOTED OTHERWISE.
2. SITE-WON BACKFILL MATERIAL TO BE FREE FROM COBBLES AND DEBRIS.
3. NON-FROST SUSCEPTIBLE TYPE C FILTER MATERIAL TO SHW CLAUSE 505 OR GRANULAR MATERIAL TO SHW CLAUSE 503.3(i).



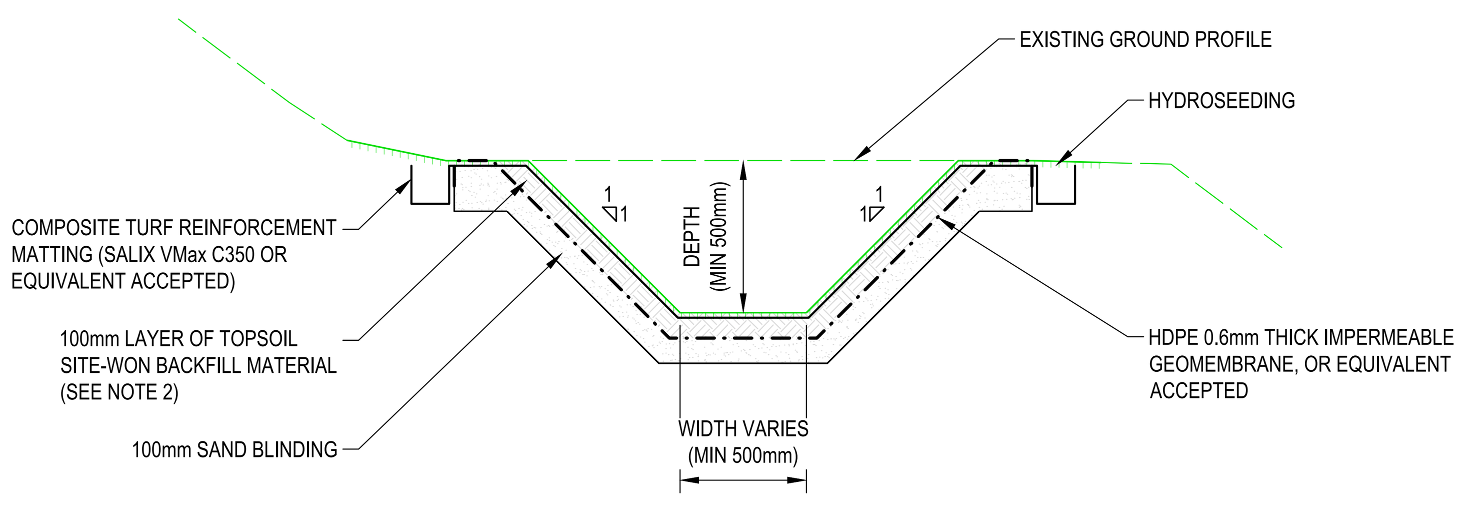

## DETAIL A
TYPICAL CROSS-SECTION FORESTRY TRACK
1:25



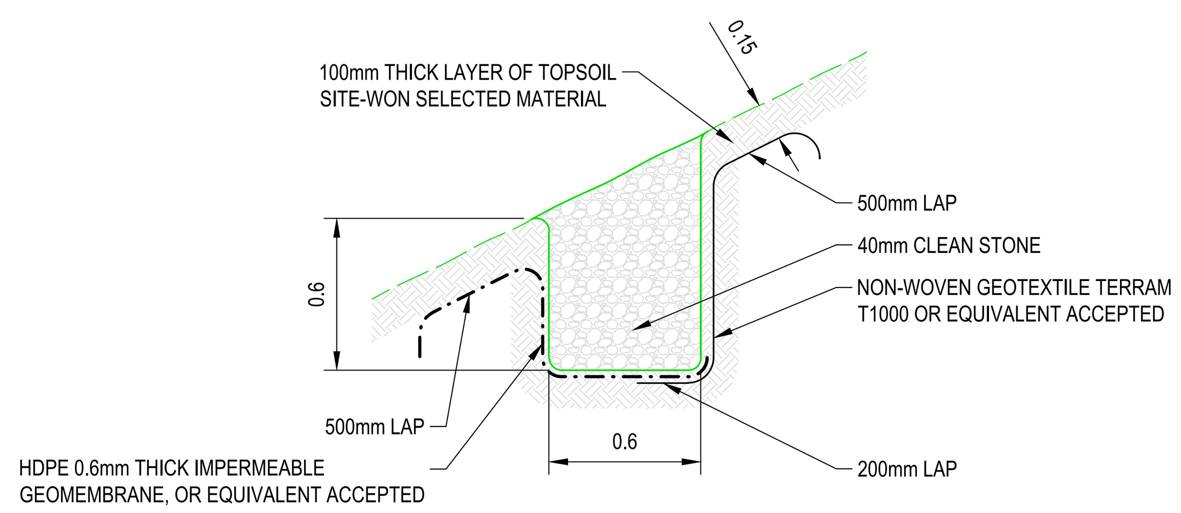

## DETAIL B
TYPICAL CROSS-SECTION BLOCKSTONE CASCADE
1:25



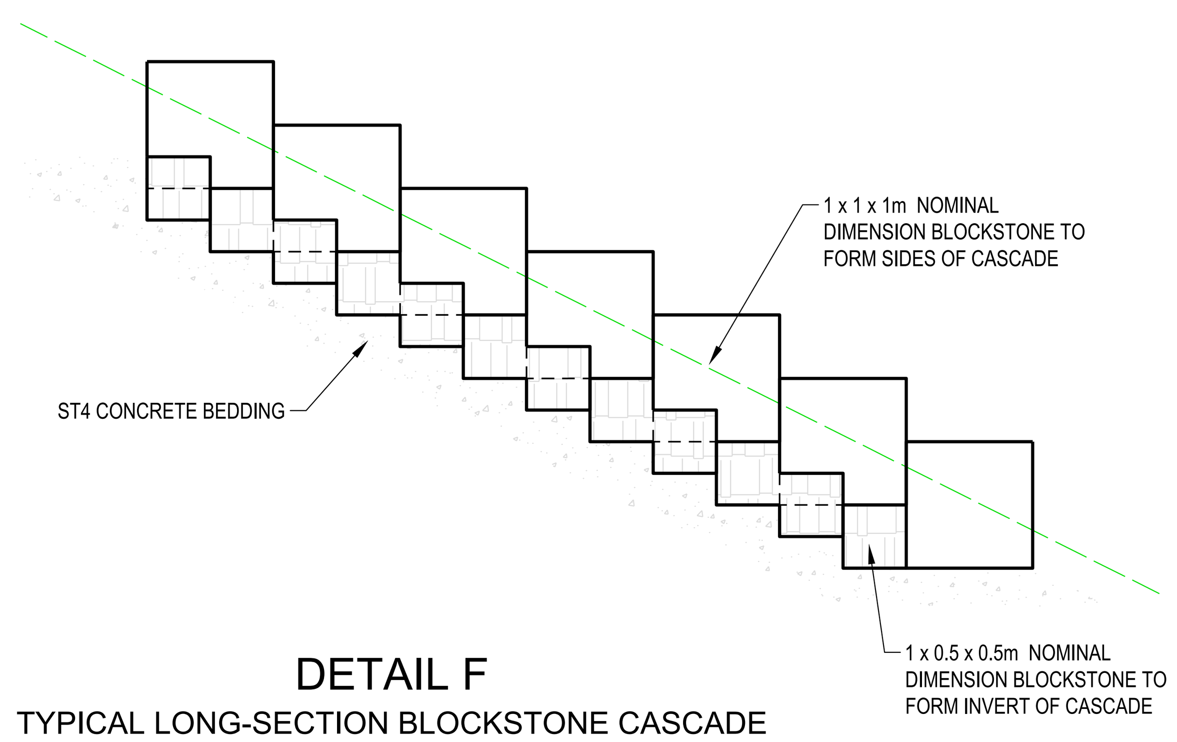

## DETAIL E
TYPICAL CROSS CHANNEL DRAINAGE CROSS-SECTION
1:25




## DETAIL C
IMPERMEABLE DITCH CROSS-SECTION
1:25




## DETAIL D
GRAVEL DRAIN (LATERAL DRAINS)
1:25




## DETAIL F
TYPICAL LONG-SECTION BLOCKSTONE CASCADE
1:50

| SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION: |
|---|
| IN ADDITION TO THE HAZARDS OR RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, THE FOLLOWING SIGNIFICANT RESIDUAL RISKS SHOULD BE NOTED. FURTHER DETAILS ARE INCLUDED IN THE CDM DESIGN RISK MANAGEMENT REGISTER |
| CONSTRUCTION: |
| TBC |
| MAINTENANCE, CLEANING AND OPERATION: |
| TBC |
| DECOMMISSIONING OR DEMOLITION: |
| TBC |

0.5m 0m 0.5m 1m
Scale 1:25
1m 0m 1m 2m 3m
Scale 1:50

| Rev | Drawn | Chkd | Rvwd | Apprvd | Date | Description |
|---|---|---|---|---|---|---|
| P01 | CF | JY | AH | AH | 08/10/24 | FOR INFORMATION |
| P02 | CF | SP | AH | AH | 01/11/24 | FOR INFORMATION 0 0 |
| P03 | RC | AA | AH | AH | 22/08/25 | FOR INFORMATION 0 0 |

Designed by: Date:

Status
S3 Suitable for Review and Comment

Client
Cyfoeth Naturiol Cymru Natural Resources Wales

Client Project No. Revision


Binnies UK Limited
Spring Lodge, 172 Chester Road, Helsby, Cheshire, WA6 0AR, UK.
Tel: +44(0)1737 774155


Project
PEN-YR-ENGLYN OPT C TCS

Drawing title
DRAINAGE FEATURES, TRACK AND ROAD DETAILS

Drawing scale: 1:25 Sheet size: A1

Drawing no. 4021526-BUK-ZZ-00-DR-C-00011 Revision P03

Parent Model: SHEET NAME

# Appendix B: Topographic Survey


Note: The limits, including the height and depths of the Works, shown in this drawing are not to be taken as limiting the obligations of the contractor under Contract.

NOTES:

1. ALL DIMENSIONS IN METRES AND ALL LEVELS IN METRES AOD, UNLESS NOTED OTHERWISE.

KEY:

- APPLICATION BOUNDARY
- MAJOR CONTOUR (5m)
- MINOR CONTOUR (1m)

10m 0m 10m 20m 30m 40m 50m 60m 70m

Scale 1:1000

| Rev | Drawn | Chkd | Rvwd | Apprvd | Date | Description |
|---|---|---|---|---|---|---|
| P01.02 | CR | --- | --- | --- | --- | |

Designed by: Date:

Status
S0 Initial Status or WIP

Client
Cyfoeth Naturiol Cymru
Natural Resources Wales

Client Project No. Revision

**Binnies UK Limited**
Spring Lodge, 172 Chester Road, Helsby, Cheshire, WA6 0AR, UK.
Tel: +44(0)1737 774155

Project
# PEN-YR-ENGLYN

Drawing title
## TOPOGRAPHIC SURVEY & CONTOURS PLAN

Drawing scale: 1:1000 Sheet size: A1

Drawing no. 4021526-BUK-ZZ-00-DR-C-00027 Revision P01.02

Parent Model: SHEET NAME

# Appendix C: Saturation Level Calculation Information

The operation of the subsurface drains has been modelled using the analysis developed by Mansur & Kaufman and detailed in the Construction Industry Research and Information Association (CIRIA) report R113, Control of ground water for Temporary Works (1986). This approach provides a methodology for estimating the output of a line of wells and the corresponding drawdown. The tip material has been considered as an unconfined aquifer. As noted previously, the permeability of the tip material varies locally which will result in corresponding variations in flow but it is considered that these calculations demonstrate that the aggregate flows will be very small.

Analysis has indicated that, provided the groundwater head within the colliery spoil remains below 5m, then slope stability should not be adversely affected. Based on the drainage layout provided in Appendix A, calculations indicate that a discharge rate of 0.003 L/s per drain, based on a spacing of 10m and drain diameter of 75mm, should be sufficient to maintain ground water well below this head.

# Appendix D: Hydraulic Modelling Report

4021526-BUK-ZZ-00-RP-NM-00001

# PEN-YR-ENGLYN

Hydraulic Modelling Report

**Project no. 4021526**

Prepared for:

Natural Resources Wales

June 2025

# Table of contents



## Details of document preparation and issue:

| Version no. | Prepared | Checked | Reviewed | Approved | Issue date | Issue status |
|---|---|---|---|---|---|---|
| P01 | Rukhsar Sirdarbeg | Ammar Ahmad<br>Ed Gower | Paul Martin | A. Humphreys | January 2025 | For Comment |
| P02 | Rukhsar Sirdarbeg | Jonathan Kean | Ed Gower | A. Humphreys | June 2025 | Final |
| | | | | | | |
| | | | | | | |

Project number: 4021526 Client's reference no.

File name: 4021526-BUK-ZZ-00-RP-NM-00001

# 1. Introduction

## 1.1 Background Information

A 1D/2D hydraulic model of the Pen-Yr-Englyn (PYE) site was built in InfoWorks ICM to assess the existing drainage network and consequently, propose enhancements. The purpose of this modelling exercise was to ensure that the surface run-off can be drained off the coal tip slope without increasing flows in the local surface water system. The site, along with its existing network modelled in InfoWorks ICM is shown in Figure 1-1.

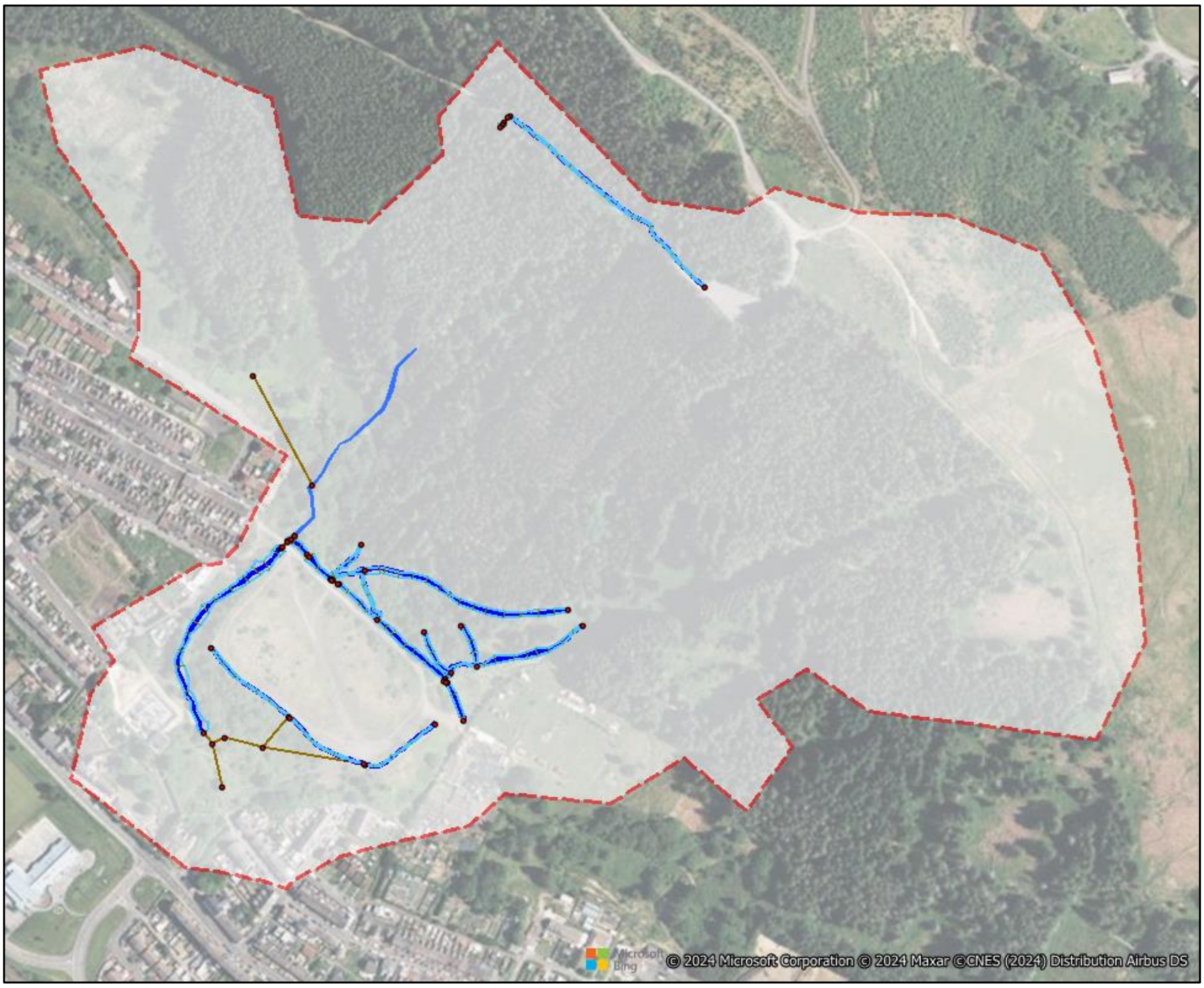



**Figure 1-1 PYE Existing Drainage Network (Extract from Bing Maps aerial imagery)**

# 2. Data

## 2.1 Topography data

A LiDAR survey with an accuracy of 0.1m was conducted for this site and used to develop the ground model. Additionally, in order to accurately represent the existing drainage channels and to increase model confidence, cross-section of the existing channels were surveyed at regular intervals of approximately 10m.

## 2.2 Rainfall Data

The FEH22 design rainfall was used in the InfoWorks ICM model and was applied as direct rainfall onto the 2D model mesh. A range of rainfall durations were used namely 30 min, 60 min, 90 min, 120 min, 180 min and 240 min. The return periods tested were as follows: 1:30yr, 30yr+climate change, 100yr and 100yr+climate change. (An uplift of 30% was added to the rainfall intensities for the climate change events).

# 3. Model Build & Validation

## 3.1 Ground Model

A 2D mesh was generated using the LiDAR data as the ground model. Local mesh zones were used to level the surface where the LiDAR was not available. These were all downstream of the site and had no effect on the drainage within the study area. Mesh level zones were also used to represent the existing drainage channel where the LiDAR detail was insufficient. The mesh triangles were set to a maximum area of $2m^2$ and a minimum area of $1m^2$. The 2D zone had the terrain sensitive meshing set to active with rainfall directly applied onto the mesh. The flow directions were analysed based on a preliminary run and the size of the 2D zone was adjusted accordingly. A Manning's value of 0.040 was assumed throughout the 2D zone to represent the coal tip surface.

## 3.2 Other Elements

### (a) Channels

The existing watercourses on the slope and around the plateau were modelled as river reaches, with cross-sectional data obtained from the topographical surveys. LiDAR data was used to accurately represent the bank lines between the surveyed cross-sections.

### (b) Culverts and drains

The culverts on the east and west side were also included in the model. The drains connecting the existing watercourses on the site to the local surface water system were modelled as 1D conduits in InfoWorks ICM.

## 3.3 Rainfall

The model was run with the existing topography and the flood extent was compared across all return periods and durations. The most critical rainfall duration was found to be 60minutes.

# 4. Baseline Results

The baseline result obtained from a M100:60 design storm is shown in Figure 4-1.

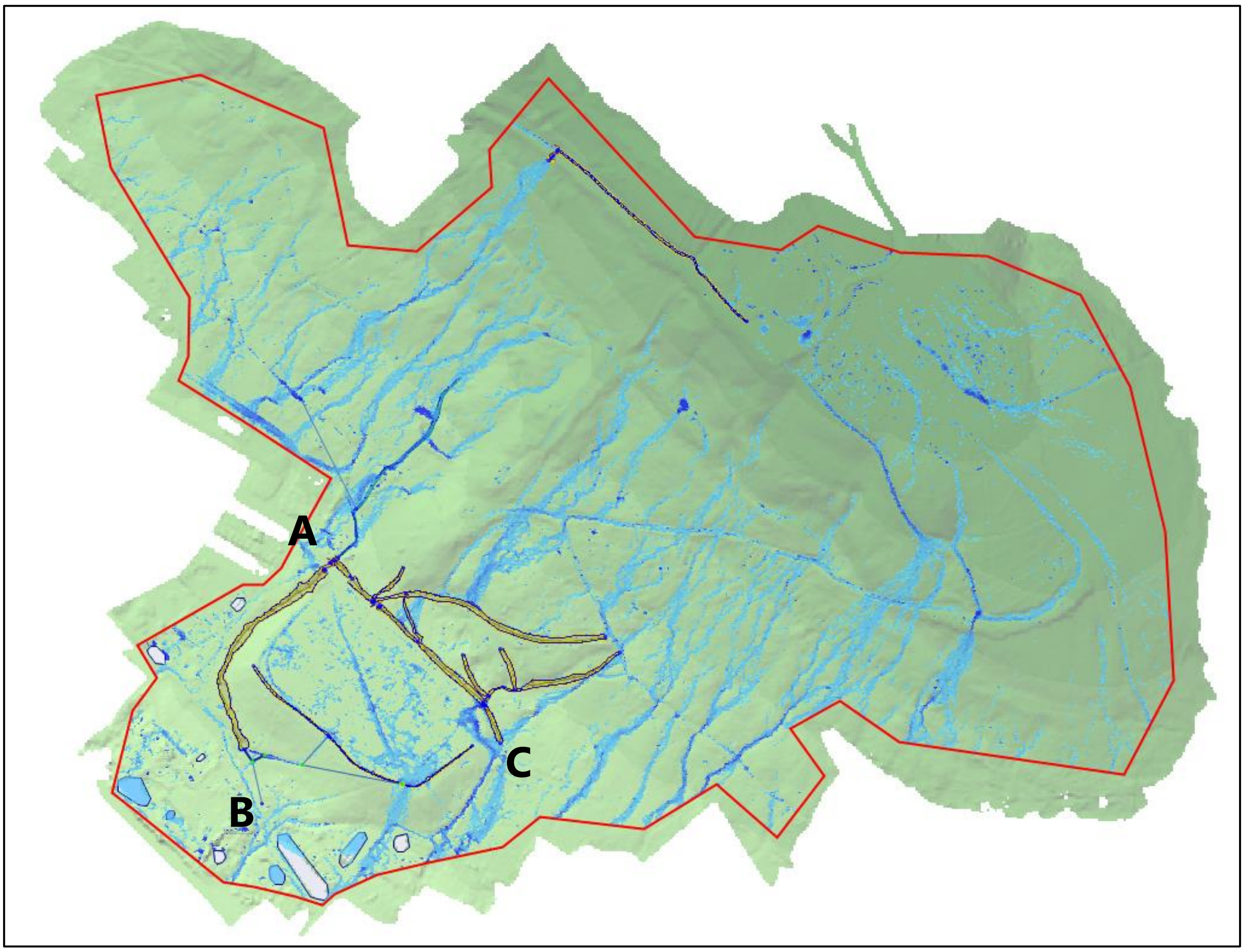



**Figure 4-1 Flow paths generated in a 100-year storm in the existing drainage network (ICM Extract)**

The flow paths generated in the model align well with the expectations based on the site's topography and existing drainage features. The flows from the north of the site enter the existing forest drains and re-emerge through the culvert on the coal tip surface. These flows then run along to the west side, with a portion being redirected to the central part of the site through the culvert to the west.

On the east side of the ridge, the flows run along the slope and merge into the natural watercourses as they make their way to the south of the site. Nevertheless, some flows deviate from the natural drainage paths and enter the forest road drains in an uncontrolled manner. Most of the flows emanating from the slope are intercepted by the channel at the top of the plateau and are diverted out of the site through Outfall C.

Meanwhile, flows from the plateau are captured by the drainage channel at the southern edge and eventually leave the site through Outfall B. This outfall also serves as the exit for flows originating from the north part of the site and the area immediately west of the ridge.

Hence, it was deduced that the observations from the model support our understanding of the site's natural drainage system. Three outfall points were chosen as control points namely A, B and C. The flows associated with each control point have been summarised in Table 4-1 below.

**Table 4-1 Peak flows at control points in the existing drainage network (l/s)**

| Return Period | Location | Existing Peak Flows (l/s) |
|---|---|---|
| 1:30 | A | 622 |
| | B | 893 |
| | C | 733 |
| 1:100 | A | 759 |
| | B | 1054 |
| | C | 887 |
| 1:30 + CC | A | 782 |
| | B | 1088 |
| | C | 919 |
| 1:100 +CC | A | 958 |
| | B | 1276 |
| | C | 1116 |

# 5. Optioneering

## 5.1 Proposed Assets Modelled

The four main elements modelled as part of the solution were the filter drains, the lateral gravel-filled trenches, the block stone cascades and the grassed ditches, these are shown on Figure 5-1.

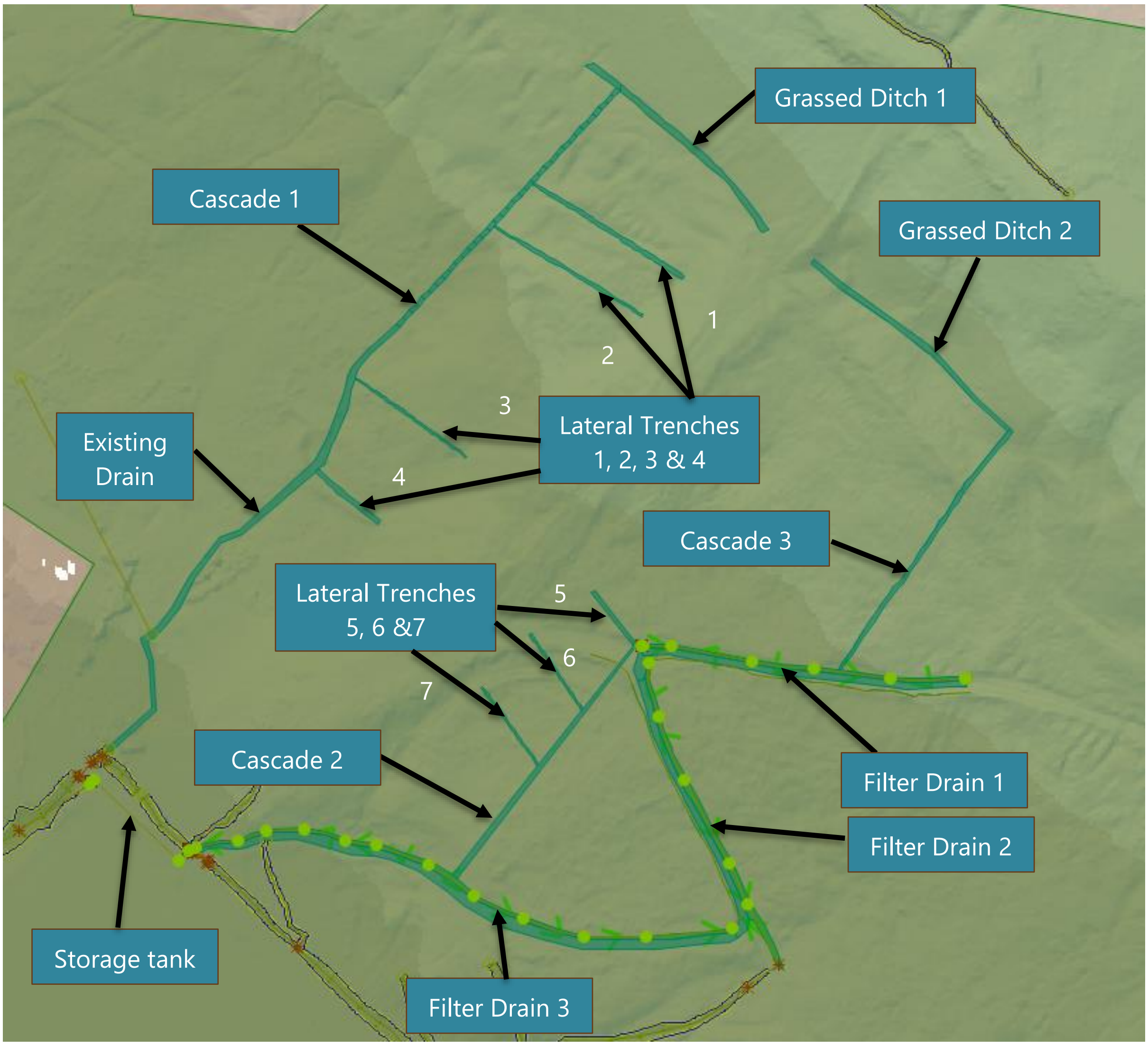



**Figure 5-1 New drainage network modelled in InfoWorks ICM (ICM Extract)**

The cascades, ditches and trenches were modelled in a similar way by using mesh level zones to lower the existing surface of the ground model. They were all modelled to be rectangular in shape. Filter drains have been modelled in line with the latest guidance for the software.

## 5.2 Results

The flow paths obtained after including the solutions are shown in Figure 5-2.

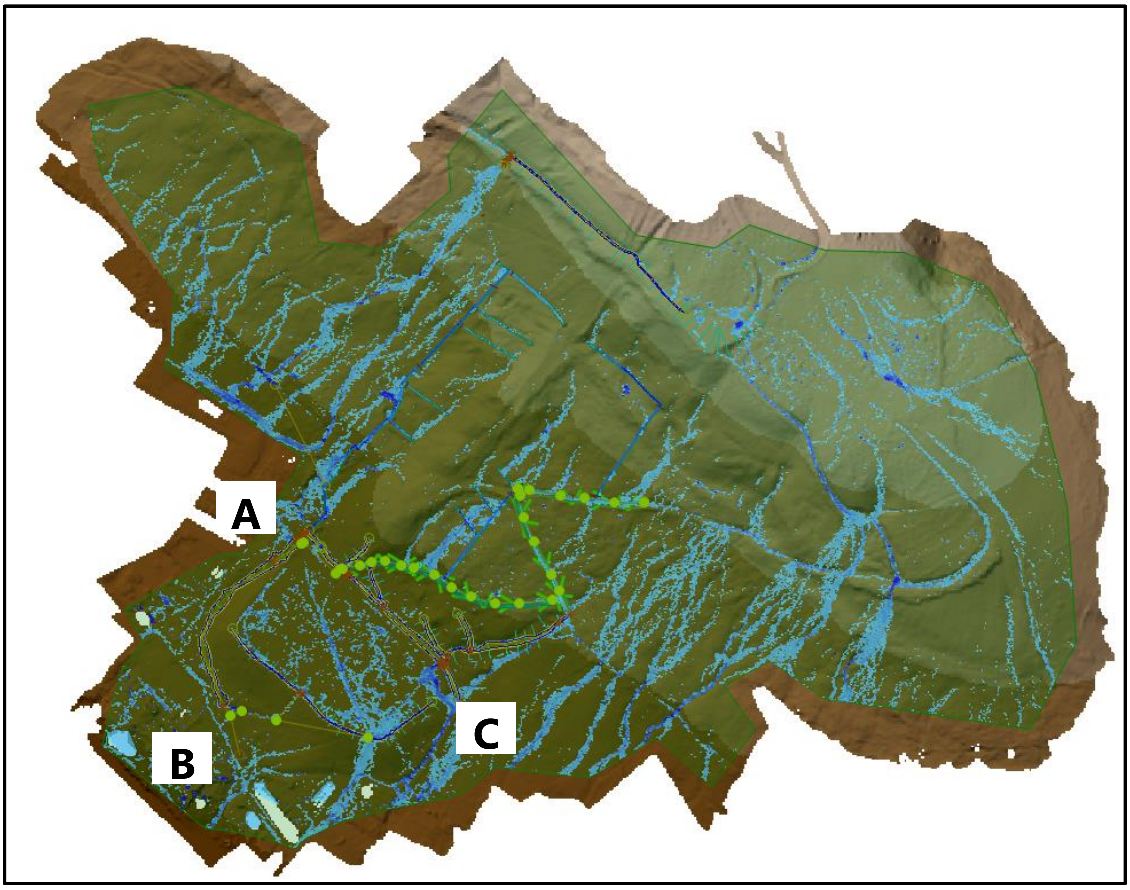



**Figure 5-2 Flow Paths generated in the 100 year storm in the updated drainage network (ICM Extract)**

On both sides of the ridge, the grassed ditches manage to catch some of the flows from the north and direct them to the cascades. Similarly, the lateral trenches can capture the previously uncontrolled flows on the slope near the ridge and divert them to the cascade and eventually to the existing drain.

On the east side of the ridge, the filter drains convey the flows to the cascade and the existing watercourse. The uncontrolled discharge in the central area is now being directed through Cascade 2 to the existing forest road drains.

At the downstream of the site as part of the solution there has been a requirement to reduce the size of one of the culverts. This acts as a restriction and reduces the flows which discharge through location B. However, on its own this would increase the flows through location C. To mitigate against this a storage tank has been included which is able to discharge by gravity.

The flows associated with each of the three control points have been summarised in **Error! Reference source not found.**. More detailed information about the flow, velocity and invert of the drainage elements are attached in Appendix A.

The proposed drainage design tries to capture as much of the overland flow as possible, however, there are areas where this has not been possible due to the location of historical mine shafts which need to be avoided. Across the site the amount of uncontrolled overland flows have been reduced.

Overall, there is no predicted increase in the volume of runoff from the site.

**Table 5-1 Flows (l/s) at control points in the updated drainage network**

| Return Period | Location | With option (l/s) | Difference to existing (l/s) |
|---|---|---|---|
| 1:30 | A | 676 | +54 |
| | B | 916 | +23 |
| | C | 731 | -2 |
| 1:100 | A | 831 | +72 |
| | B | 1041 | -13 |
| | C | 867 | -20 |
| 1:30 + CC | A | 852 | +70 |
| | B | 1069 | -19 |
| | C | 892 | -27 |
| 1:100 +CC | A | 1082 | +124 |
| | B | 1202 | -74 |
| | C | 1038 | -78 |

To understand the performance in the new storage pipe Table 5-2 shows the peak water levels and the amount of freeboard within the tank for each design storm. The results show that the freeboard is above the minimum requirement of 200mm.

**Table 5-2 – Peak water levels in the storage tank**

| Return Period | Peak Water Level (mAD) | Freeboard (m) |
|---|---|---|
| 1:30 | 212.684 | 1.676 |
| 1:100 | 213.062 | 1.300 |
| 1:30 + CC | 213.155 | 1.205 |
| 1:100 + CC | 213.841 | 0.519 |

## 5.3 Limitations and Model Improvements

Some of the key model limitations that need to be considered are as follows:

- The model has not been verified against any measured information. If there is any data available for previous flooding events which could be used to test the model then this would improve the confidence.

- Further refinements will be brought to the model as the detailed design proceeds to improve the representation of the various drainage elements.

- The design approach focused on keeping the flows downstream of the plateau unchanged after putting in the drainage solution. As such, the capacity of the drainage pipes downstream of the plateau before connecting to the local surface water network was not assessed in this model.

# 6. Conclusions & Recommendations

A 1D/2D hydraulic model of the Pen-Yr-Englyn (PYE) site was built in InfoWorks ICM to assess the existing drainage network and consequently, propose improvements. A combination of LiDAR and topographic data was used to develop the ground model and the existing drainage network. Various SuDS elements such as filter drains, gravel-filled trenches, blockstone cascades and grassed ditches were incorporated in the model to design a solution.

The proposed design has been developed to improve the overall drainage off the site and to improve the efficiency of the flows getting off the site. There has been a requirement to include a storage tank at the downstream end of the slope. This has been included to reduce the peak flows which would be leaving the site. Recommendations to improve model accuracy consist of undertaking a validation exercise using any available information and refinement of the modelling of the proposed solutions.

# APPENDICES

## Appendix A: Velocity, flow and inverts of drainage elements

More detailed information regarding the different elements have been attached in Figure 6-1 and Table 6-1.

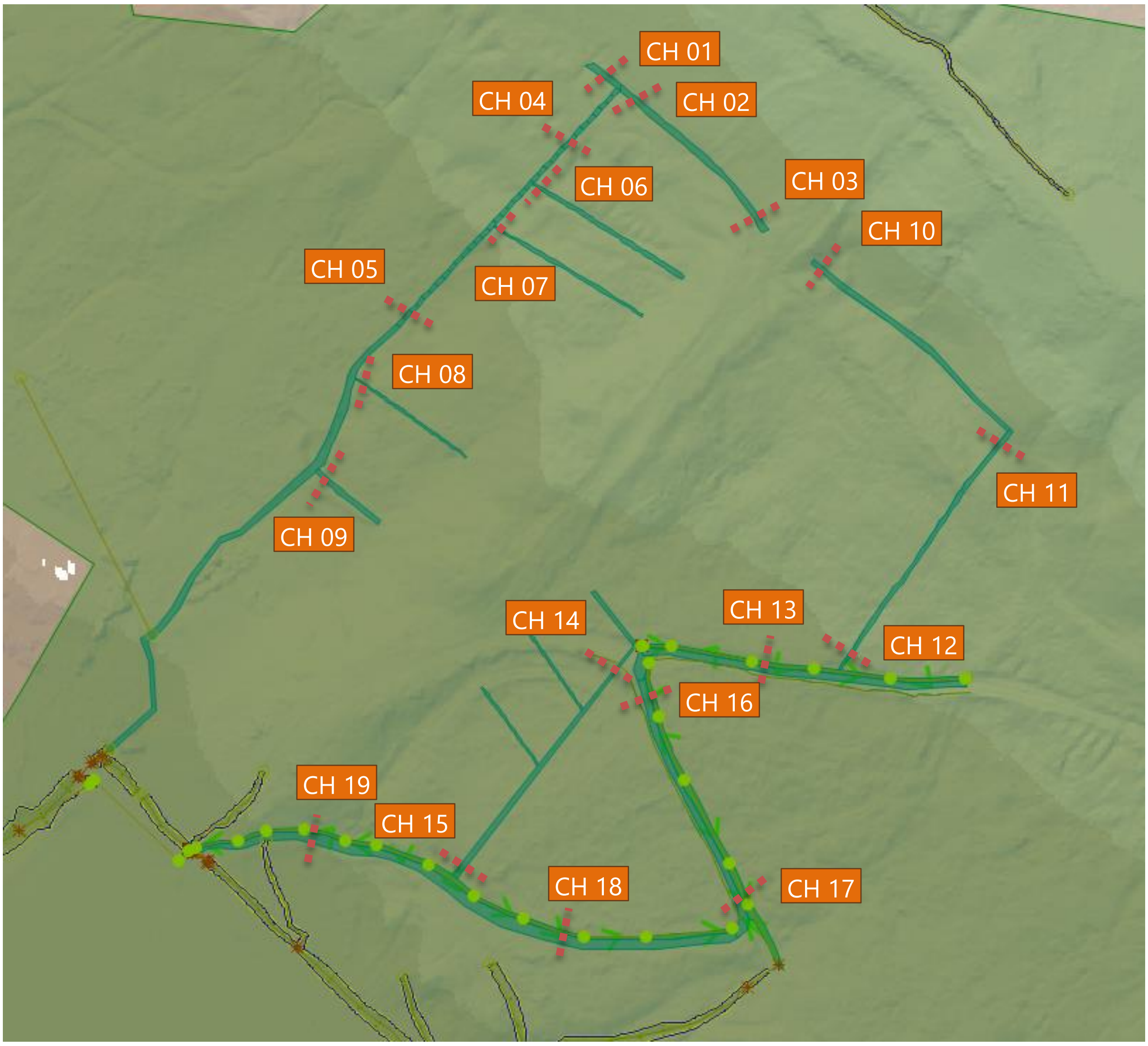



**Figure 6-1 Drainage layout schematic**

**Table 6-1 Flow, velocity and inverts in drainage elements**

| Element | Location | Invert Level (mAOD) | Velocity (m/s) | | | | Flow ($m^3/s$) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1:30 | 1:100 | 1:30CC | 1:100CC | 1:30 | 1:100 | 1:30CC | 1:100CC |
| Drainage Ditch 1 | CH01 | 301.656 | 0.12 | 0.14 | 0.14 | 0.16 | 0.007 | 0.009 | 0.009 | 0.011 |
| | CH02 | 292.713 | 0.96 | 1.07 | 1.09 | 1.21 | 0.134 | 0.172 | 0.18 | 0.231 |
| | CH03 | 296.941 | 0.21 | 0.24 | 0.25 | 0.27 | 0.003 | 0.004 | 0.005 | 0.006 |
| Cascade 1 | CH04 | 283.982 | 0.95 | 1.06 | 1.08 | 1.19 | 0.141 | 0.181 | 0.189 | 0.239 |
| | CH05 | 247.444 | 1.24 | 1.43 | 1.46 | 1.68 | 0.298 | 0.382 | 0.398 | 0.508 |
| Trenches 1-4 | CH06 | 274.785 | 1.11 | 1.20 | 1.22 | 1.33 | 0.055 | 0.07 | 0.073 | 0.094 |
| | CH07 | 266.997 | 0.60 | 0.65 | 0.66 | 0.71 | 0.036 | 0.044 | 0.046 | 0.057 |
| | CH08 | 243.212 | 1.26 | 1.42 | 1.45 | 1.63 | 0.06 | 0.077 | 0.08 | 0.103 |
| | CH09 | 235.36 | 1.03 | 1.14 | 1.16 | 1.27 | 0.092 | 0.119 | 0.124 | 0.158 |
| Drainage Ditch 2 | CH10 | 298.327 | 0.03 | 0.03 | 0.03 | 0.04 | 0.001 | 0.002 | 0.002 | 0.002 |
| | CH11 | 297.187 | 0.85 | 0.96 | 0.99 | 1.12 | 0.178 | 0.229 | 0.239 | 0.306 |
| | CH12 | 263.075 | 1.20 | 1.38 | 1.42 | 1.63 | 0.213 | 0.273 | 0.286 | 0.366 |
| Filter Drain 1 | CH13 | 261.562 | 3.53 | 3.79 | 3.84 | 4.08 | 0.155 | 0.184 | 0.189 | 0.221 |
| Cascade 2 | CH14 | 250.239 | 1.87 | 2.10 | 2.14 | 2.43 | 0.44 | 0.544 | 0.562 | 0.719 |
| | CH15 | 225.892 | 1.13 | 1.26 | 1.28 | 1.46 | 0.252 | 0.315 | 0.326 | 0.417 |
| Filter Drain 2 | CH16 | 250.796 | 4.2 | 4.69 | 4.8 | 5.08 | 0.153 | 0.194 | 0.204 | 0.232 |
| | CH17 | 236.446 | 4.48 | 4.64 | 4.62 | 4.61 | 0.211 | 0.273 | 0.287 | 0.333 |
| Filter Drain 3 | CH18 | 227.518 | 2.33 | 2.55 | 2.6 | 2.78 | 0.169 | 0.221 | 0.233 | 0.288 |
| | CH19 | 217.355 | 3.52 | 3.8 | 3.84 | 4.11 | 0.743 | 0.948 | 0.988 | 1.243 |