Pen Y Gwaith (Upper & Lower) Flood Consequence Modelling

Final Report

September 2020

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Revision History

Revision Ref/Date	Amendments	Issued to
v1.0 / August 2020	Draft Report	Liam McCarthy
v1.0_Final / September 2020	Final Report (no changes from draft)	Jack Lewis-Roberts

Contract

This report describes work commissioned by Liam McCarthy, on behalf of Natural Resources Wales, by an instruction dated 16 April 2020. Claire French of JBA Consulting carried out this work.

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Purpose

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1 Introduction

1.1 Context

Pen Y Gwaith (Upper & Lower), which is owned by Natural Resources Wales (NRW), has a capacity of approximately 12,519 m^3 (JBA Consulting, 2020). It is registered as a Category B dam under the Reservoirs Act 1975 (as amended by the Flood and Water Management Act 2010). A flood study, updated by JBA in May 2020, shows that the reservoir does not meet the recommended flood safety standards. Future remedial options for Pen Y Gwaith (Upper & Lower) are, therefore, being considered. To help inform the selection of the preferred option, NRW has commissioned JBA Consulting to undertake a flood consequence analysis (FCA).

This report summarises the methodology and findings of the FCA. The aim of the FCA is to determine the flood risk impacts of two options, compared to the existing baseline; the three dam conditions are outlined in Table 1-1. The objectives of the FCA are as follows:

- Derive reservoir inflow hydrographs for the 10, 30, 100 + climate change (CC), and 1,000-year return periods;
- Use the 1D hydraulic model from the flood study to route the inflow hydrographs through Pen Y Gwaith (Upper & Lower) for the three dam conditions;
- For each condition and return period, determine the storm duration that gives the maximum reservoir level, reflecting reservoir attenuation and lag;
- Quantify the difference in peak flow between the Baseline (QpB) and Option (QpO) outflow hydrographs for each return period event;
- Run JBA's existing reservoir flood mapping (RFM) model for both the baseline condition and the worst-performing option, for the four return periods of interest, and compare downstream flood impacts; and
- For the preferred option, use the existing routing model to determine whether spillway blockage, during the 100-year + CC event, could lead to overflowing of the dam.

Table 1-1 Pen Y Gwaith (Upper & Lower) dam conditions

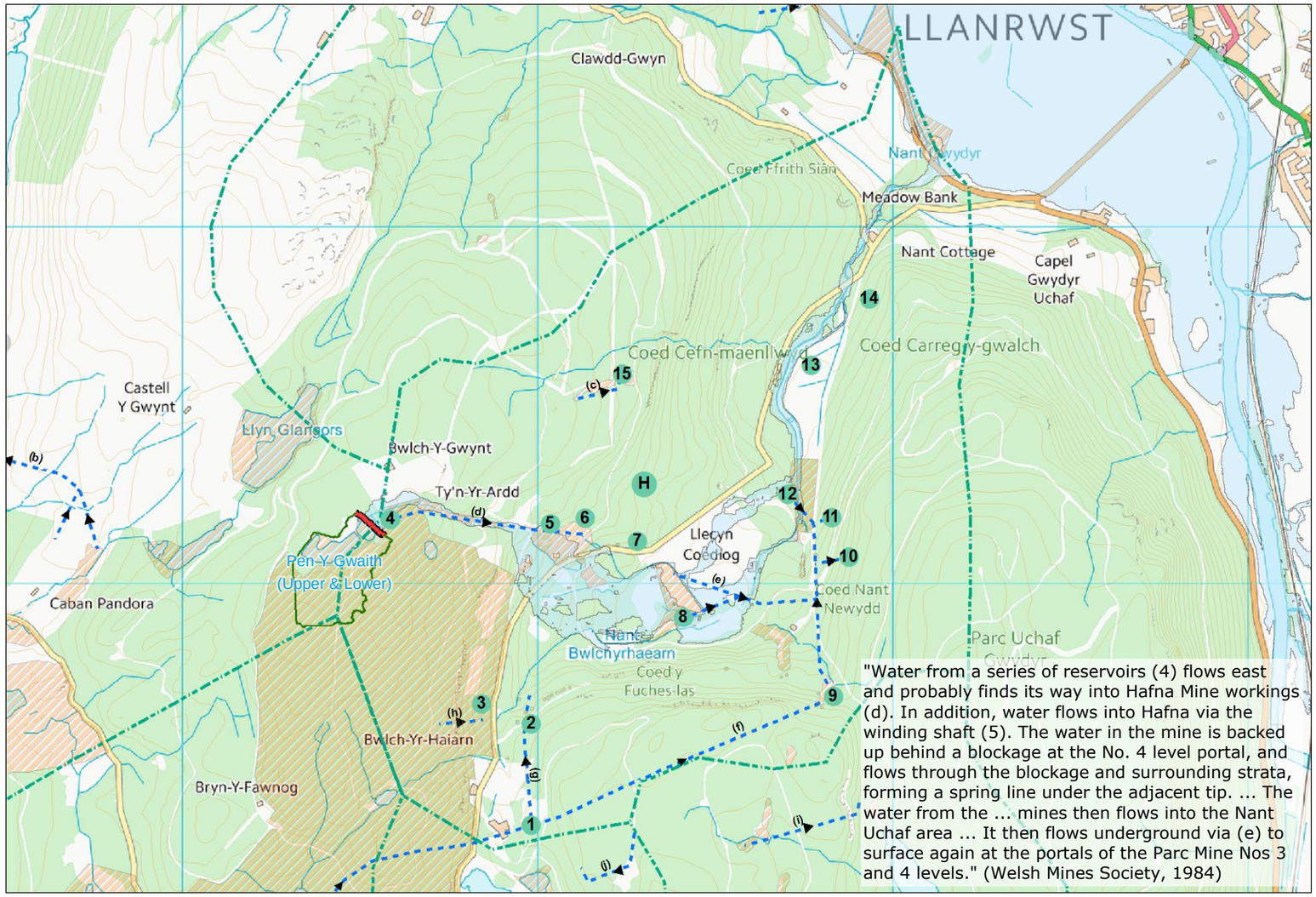
Condition*	Description
Baseline	The existing spillway condition
Option 1a	Modify spillway width to 1.32 m and raise dam, but retain current top water level
Option 1c	Modify spillway width to 5.00 m and raise dam, but retain current top water level

*As part of the 2020 flood study, JBA identified 14 different potential combinations of spillway width and dam height, referenced a to n. From these 14 options, NRW has selected a and c to be investigated further in this FCA

1.2 Overview of the study area

Pen Y Gwaith (Upper & Lower) lies within Gwydyr Forest in Snowdonia, approximately 3 km to the south-west of the market town of Llanrwst (NGR SH 77420 60090; Figure 1-1). It is one of a number of reservoirs within the forest used historically to supply water for metal mine workings. The Upper reservoir was constructed in the late 1800s, followed by the Lower reservoir in the early 1900s. Today, the reservoir is used for private water supply to isolated properties and is popular with dog walkers.

Pen Y Gwaith (Upper & Lower) is formed by three earthfill embankments. The Upper reservoir is retained by the West and Central dams, while the Lower reservoir is impounded by the North-East dam. The Central dam, which separates the Upper and Lower reservoirs, is in a dilapidated and leaking state. As a result, the two water bodies effectively operate as one and have the same water level (e.g. 304.97 m AOD on 6 September 2018). This FCA concerns the North-East dam only, shown in Figure 1-1a, since it is the lowest of the three dams and incorporates the main spillway.



"Water from a series of reservoirs (4) flows east and probably finds its way into Hafna Mine workings (d). In addition, water flows into Hafna via the winding shaft (5). The water in the mine is backed up behind a blockage at the No. 4 level portal, and flows through the blockage and surrounding strata, forming a spring line under the adjacent tip. ... The water from the ... mines then flows into the Nant Uchaf area ... It then flows underground via (e) to surface again at the portals of the Parc Mine Nos 3 and 4 levels." (Welsh Mines Society, 1984)

North-East dam

Pen Y Gwaith (Upper & Lower) catchment

Mine surface catchment areas

Underground drainage routes via mine workings

Dam break flood extent (Wet Day scenario)

SSSI

10 m contours (OS Terrain 50)

N

0 250 500 m

Notes from Welsh Mines Society (1984):

Mine surface catchment area H:
1) Llanrwst Mine - Dressing floors and shafts
2) Llanrwst Mine - Deep drainage level
3) Vale of Conwy Mine - Adit
4) Upper Hafna - Reservoirs
5) Hafna Mine - Winding shaft
6) Hafna Mine - No. 4 level and tips
7) Hafna Mine - No. 5 level
8) Reservoir Lode - Open stope and Nant Uchaf upper tailing lagoon for Parc Mine
9) Parc Mine - Nos. 1 and 2 levels and Fuches Las area
10) Cilstent Mine - Adit
11) Parc Mine - No. 3 level
12) Parc Mine - No. 4 level
13) Parc Mine - Capped shaft
14) Parc Mine - No. 5 level
15) Ffrith Sian Mine - Adit

Figure 1-1 Study area

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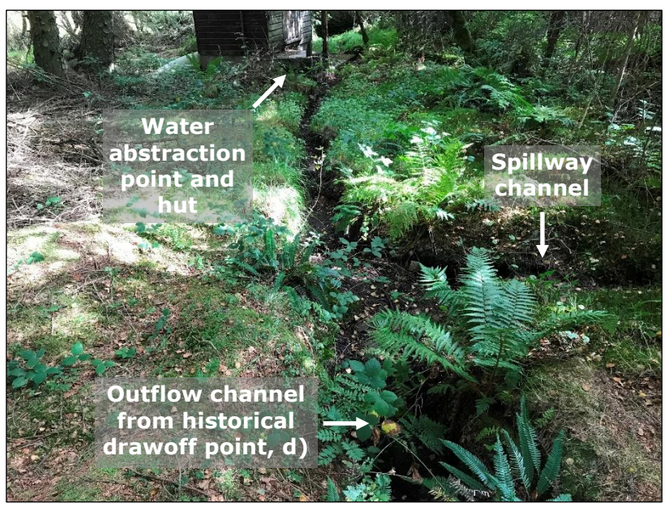

c) Outflowing stream at confluence with spillway channel, upstream of water abstraction point

a) The North-East dam

b) Emergency overflow spillway (running from bottom left to middle right)

d) Repaired breach at historical drawoff point

An emergency overflow spillway is located at the right hand (southern) end of the North-East dam (Figure 1-1b). It is a natural-lined channel, with a base width of around 1.3 m and top width of 5.4 m. A low spot, created by an uprooted tree towards the left hand (northern) end of the dam, has been temporarily repaired (Figure 1-1d). The position of this repaired low spot coincides with a historical drawoff point, marked by a sluice on the 1913 OS County Series (and some later OS map editions). An outlet channel runs north-eastwards from here. It is joined on its right bank by the spillway channel, approximately 15 m downstream of the dam (Figure 1-1c). A water abstraction point, with associated hut, is located on the left bank of the merged channel a further 8 m downstream.

There are a few properties situated adjacent to the outflowing stream, at Llecyn Coediog approximately 1 km to the south-east of the reservoir (at NGR SH 78610 60055). RFM, undertaken previously by JBA Consulting in accordance with the Environment Agency's 2016 RFM specification, has shown that these properties are at risk of flooding from failure of the North-East dam. A series of mine spoil heaps, shown in orange in Appendix A, also lie within the predicted extent of a dam break flood. Some of these spoil heaps have been included within the Gwydyr Forest Mines Site of Special Scientific Interest (SSSI) designation (Figure 1-1), owing to the distinctive plant assemblages that they support (Countryside Council for Wales, 2002).

2 Methodology

The FCA methodology comprises three key elements: hydrograph generation, reservoir routing and RFM. These elements are summarised below.

2.1 Hydrograph generation

Reservoir flood inflow hydrographs have been derived, for all return periods of interest, using the Revitalised Flood Hydrograph rainfall-runoff method version 2.2 (ReFH2). Hydrographs for the 1,000-year return period have also been generated using the FSR/FEH rainfall-runoff model. This is in light of concerns that the suitability of using the ReFH2 software to estimate the 1,000-year return period for reservoir safety purposes has not been evaluated fully. Both rainfall-runoff models have been based on the catchment descriptor values presented in Table 4-1 of JBA's (2020) flood study, together with FEH13 rainfall data.

Since the surface area of Pen Y Gwaith (Upper & Lower) occupies approximately 18 per cent of the catchment area, no losses have been applied to the rain falling on the surface of the reservoir. This rain has, instead, been added directly to the inflow hydrographs (the reservoir area having been excluded from the catchment used in the rainfall-runoff models). Hydrographs have been generated for the 10, 30, 100 and 1,000-year return periods. Each return period has been simulated for a range of storm durations. A 30 per cent climate change uplift has been applied to the 100-year hydrographs, reflecting the central estimate of total change in peak river flow anticipated by the 2080s in West Wales (Welsh Government, 2016).

2.1.1 ReFH2.2 versus ReFH2.3

Since JBA first completed the flood study in January 2019, a new version of the ReFH software (version 2.3) has been released. Key enhancements within the ReFH2.3 model include closing of the water balance (i.e. total event runoff depth cannot exceed rainfall depth) and incorporation of a new BFIHOST19 descriptor. This latest software version gives lower reservoir inflows for Pen Y Gwaith (Upper & Lower) than the ReFH2.2 model, as illustrated in Figure 2-1. The differences are due to changes in how baseflow recharge (BR), together with initial soil moisture content (C_{ini}) and maximum soil moisture capacity (C_{max}), is derived. In impermeable catchments like Pen Y Gwaith (Upper & Lower) (BFIHOST19 < 0.5), ReFH2.3 calculates BR dynamically in order to close the water balance over an event. For consistency with the flood study, ReFH2.2, which estimates BR from catchment descriptors, has been used in this FCA, representing a slightly conservative approach.

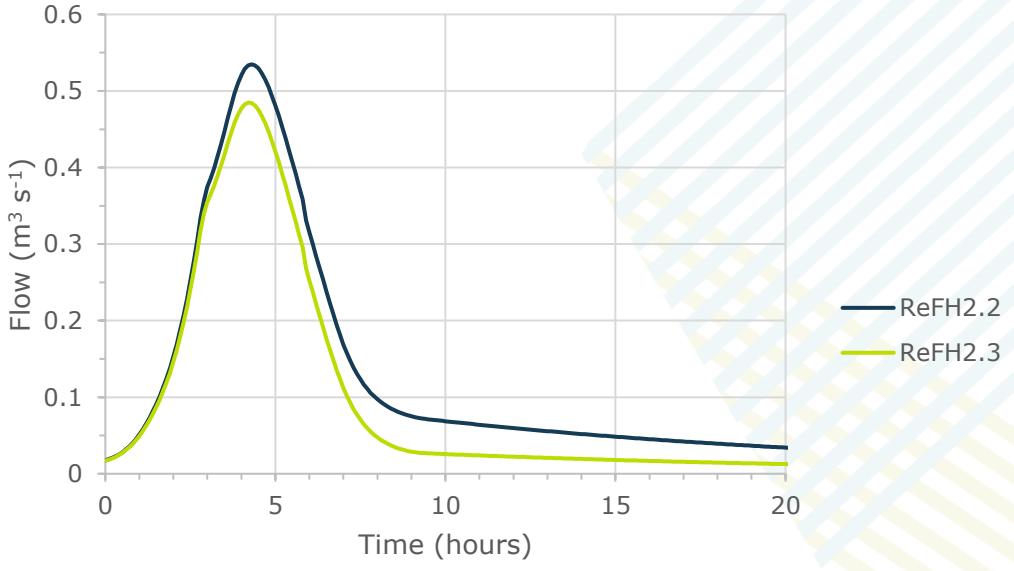

Figure 2-1 Comparison of results between ReFH2.2 and ReFH2.3

(1,000-year inflow to Pen Y Gwaith (Upper & Lower), based on a 5.9-hour storm duration)

2.2 Reservoir routing

The 1D hydraulic model, produced by JBA (2020) as part of the flood study, has been used to route the reservoir inflow hydrographs through Pen Y Gwaith (Upper & Lower) for the baseline case and future options. A top water level of 305.513 m AOD has been adopted throughout, reflecting the invert elevation of the current emergency overflow spillway. As mentioned in Section 1.2, temporary repairs have been made to a low spot on the dam crest. It has been assumed that this repaired section lies at the same elevation as the spillway invert.

Options 1a and 1c correspond to the like-named options considered in Section 5 of the 2020 flood study, although the spillway width in Option 1c has been reduced slightly (from 5.35 to 5.00 m) in line with NRW's specifications. The side walls of the spillway have been set as vertical in both options, with a weir coefficient of 1.5, as per the flood study, on the assumption that the surface condition of the dam and spillway will be improved as part of any future works.

The routing model has also been used to determine whether spillway blockage could lead to overflowing of the dam during the 100-year + CC event. A 50 per cent bottom-up blockage proportion has been applied to the spillway in Options 1a and 1c. This blockage proportion corresponds roughly to an accumulation of drift below a 20 cm diameter log, extending across the full width of the spillway, at the 100-year + CC peak water level. It is based loosely on latest blockage management guidance, published by the Environment Agency, for open channels (Benn *et al*, 2019), and is considered to represent a credible extreme scenario.

2.2.1 Identification of optimal storm duration

The routing models have been run for a range of storm durations to identify the optimal duration for each dam condition and return period, i.e. the duration that gives the maximum reservoir level taking account of reservoir attenuation and lag. The results are summarised in Table 2-1 and illustrated in Figure 2-2. The optimal duration decreases with increasing flood recurrence interval, as expected, for all three dam conditions.

Table 2-1 Optimal storm duration (hours) by dam condition and return period

Condition	10-year	30-year	100-year + CC	1,000-year	
				ReFH2	FSR/FEH
Baseline	9.3	8.5	6.9	5.9	2.3
Option 1a	17.5	14.3	9.1	8.1	5.7
Option 1c	9.1	8.7	7.7	6.3	2.3

2.3 RFM

JBA's existing RFM model, produced for NRW in January 2019, has been used to provide a strategic assessment of the downstream flood risk associated with Options 1a and 1c, in comparison to the baseline case. A few minor changes have been made to the model set-up for the purposes of this FCA, as outlined below and illustrated in Figure 2-3:

- The 450 mm diameter culvert under the first track crossing, downstream of the dam, has been added as an ESTRY component. However, it is important to bear in mind that there is limited channel definition in the DTM upstream of the culvert, which contributes to overtopping of the track.
- The outflow hydrographs from the 1D routing model for the baseline case have been entered into the RFM model at the right-hand (southern) end of the dam, in the position of the existing emergency overflow spillway.
- The reservoir outflow hydrographs for the future options have been entered into the RFM model immediately upstream of the first track crossing. This reflects the fact that the new spillway is likely to be positioned at the left-hand (northern) end of the dam, to avoid NRW vehicles having to cross the spillway for maintenance work (e.g. mowing grass and removing brush). It will then be most practicable to connect the

Figure 2-2 Identification of the optimal storm duration

new spillway channel into the existing outlet channel near the track crossing.[1] It has been assumed that the new spillway channel will contain all of the reservoir outflow, at least up to and including the 1,000-year return period event.

- The fluvial inputs, from the catchment downstream of the reservoir, have been updated to reflect the current four return periods of interest and associated storm durations. It should be noted that a high-level approach to deriving these inflows has been taken, consistent with the Environment Agency's RFM specification.
- Fluvial inflows derived for node PenNE01 have been apportioned between this location and PenNE01us, according to catchment area. (Other fluvial inflow locations, further downstream, have remained unchanged from the original RFM model.)
- In order to allow direct comparison of results between the baseline case and the future options for a given return period, the RFM model has been run for the same storm duration for all three dam conditions. The durations adopted are the optimal storm durations identified in Table 2-1 for the baseline case. Justification for this approach is given in Section 3.

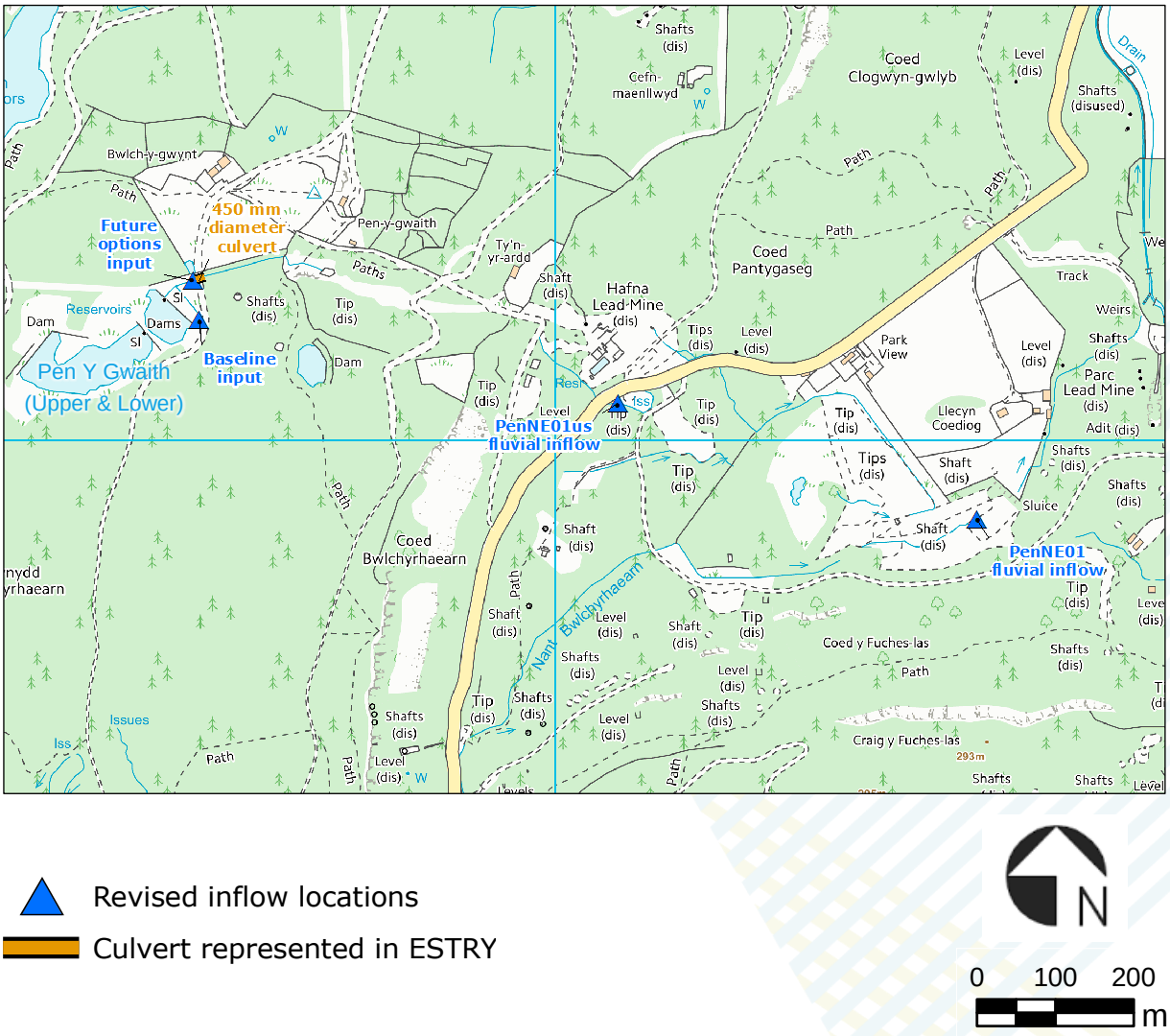

Figure 2-3 Location of changes to the original RFM model set-up

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[1] NRW, personal communication, 7 July 2020

3 Results

The results of the FCA are presented in the tables and figures included in this section and Appendix B. The following key observations can be made:

- Using the ReFH2 hydrology, Option 1a (1.32 m wide spillway) results in up to a 36 per cent decrease in peak reservoir outflow, compared to the baseline case. This is due to the smaller spillway capacity of Option 1a and the raised dam height which prevents overflowing of the dam.
- Option 1c (5.0 m wide spillway) also reduces peak reservoir outflow, although to a much lesser extent than Option 1a due to its greater spillway capacity. The reduction afforded by Option 1c, compared to the baseline case, ranges from 2 per cent in a 10-year event to 8 per cent in a 1,000-year event.
- Larger reductions in the 1,000-year peak outflow are observed, under both Options 1a and 1c, if the FSR/FEH hydrology is used instead of ReFH2. This reflects the higher peak reservoir inflows given by the FSR/FEH method, and the subsequent restriction of these flows at the reservoir exit.
- Near the start of a flood event, reservoir outflow is slightly higher under Option 1c than in the baseline case. This stems from the fact that, at relatively low flows, Option 1c has a greater spillway capacity; the total spill width at the invert elevation of 305.513 m AOD is 1.74 m in the baseline case and 5 m in Option 1c. The effect diminishes as reservoir level rises and the extent of dam overflow in the baseline case increases.
- There is no change in the total volume of reservoir outflow between the baseline case and the future options, since the spillway invert elevation remains the same in all three of the dam conditions being tested. (Zero change can be demonstrated if the routing model is run for more than 50 hours.)

Table 3-1 Comparison of reservoir outflow ($m^3 s^{-1}$) among the three dam conditions, for a range of storm durations

a) 10-year, 30-year and 100-year + CC events

Scenario	10-year			30-year			100-year+CC		
	9.3 hrs	17.5 hrs	9.1 hrs	8.5 hrs	14.3 hrs	8.7 hrs	6.9 hrs	9.1 hrs	7.7 hrs
Baseline peak outflow (QpB)	0.162	0.148	0.162	0.229	0.209	0.229	0.422	0.415	0.421
Option 1a peak outflow (QpO1a)	0.106	0.113	0.106	0.149	0.153	0.150	0.276	0.286	0.282
Percentage change: Option 1a vs Baseline	-34%	-23%	-34%	-35%	-27%	-34%	-35%	-31%	-33%
Option 1c peak outflow (QpO1c)	0.159	0.145	0.159	0.218	0.202	0.218	0.392	0.392	0.393
Percentage change: Option 1c vs Baseline	-2%	-2%	-2%	-5%	-3%	-5%	-7%	-6%	-7%
Peak fluvial inflow (lumped at PenNE01)	1.699	1.530	1.702	2.351	2.151	2.347	4.291	4.162	4.247
(QpB - QpO1a) as % of peak fluvial inflow	3%	2%	3%	3%	3%	3%	3%	3%	3%
(QpB - QpO1c) as % of peak fluvial inflow	0%	0%	0%	0%	0%	0%	1%	1%	1%

b) 1,000-year event

Scenario	1,000-year ReFH2			1,000-year FSR/FEH	
	5.9 hrs	8.1 hrs	6.3 hrs	2.3 hrs	5.7 hrs
Baseline peak outflow (QpB)	0.530	0.513	0.528	0.711	0.629
Option 1a peak outflow (QpO1a)	0.338	0.352	0.343	0.275	0.307
Percentage change: Option 1a vs Baseline	-36%	-31%	-35%	-61%	-51%
Option 1c peak outflow (QpO1c)	0.488	0.482	0.489	0.595	0.533
Percentage change: Option 1c vs Baseline	-8%	-6%	-7%	-16%	-15%
Peak fluvial inflow (lumped at PenNE01)	5.553	5.301	5.518	8.659	6.837
(QpB - QpO1a) as % of peak fluvial inflow	3%	3%	3%	5%	5%
(QpB - QpO1c) as % of peak fluvial inflow	1%	1%	1%	1%	1%

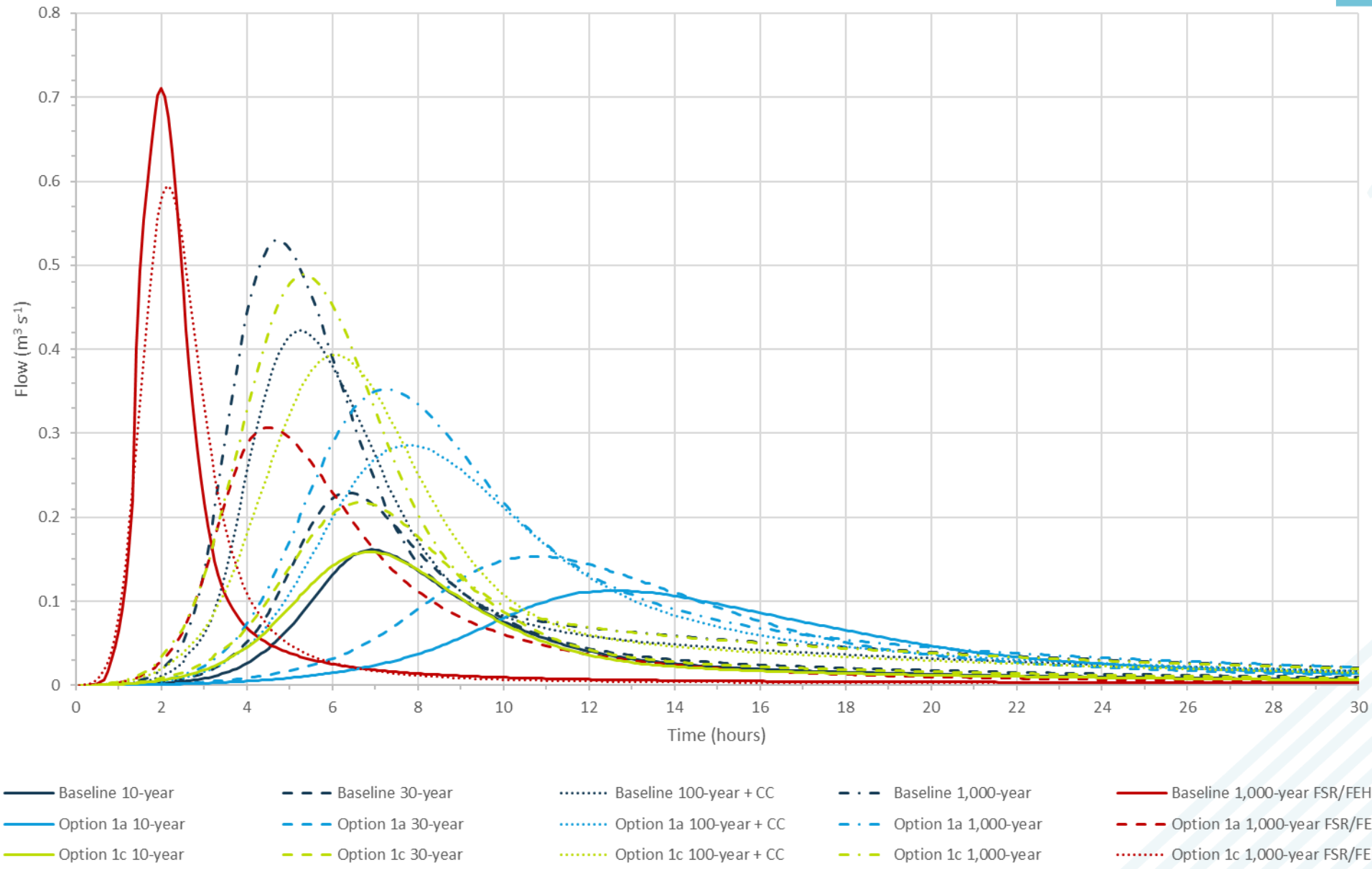


Figure 3-1 Reservoir outflow, based on the optimal storm durations specific to each dam condition

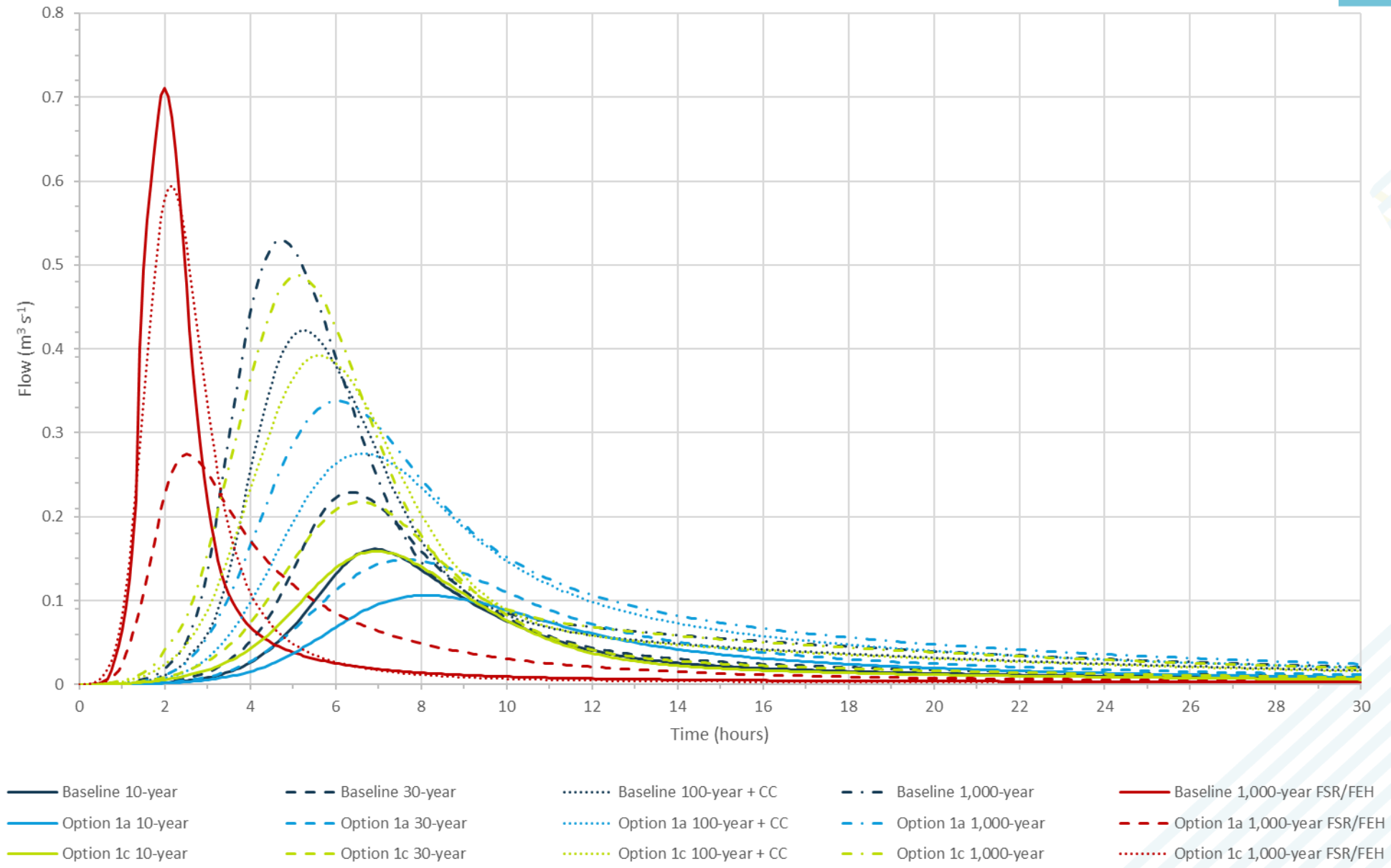
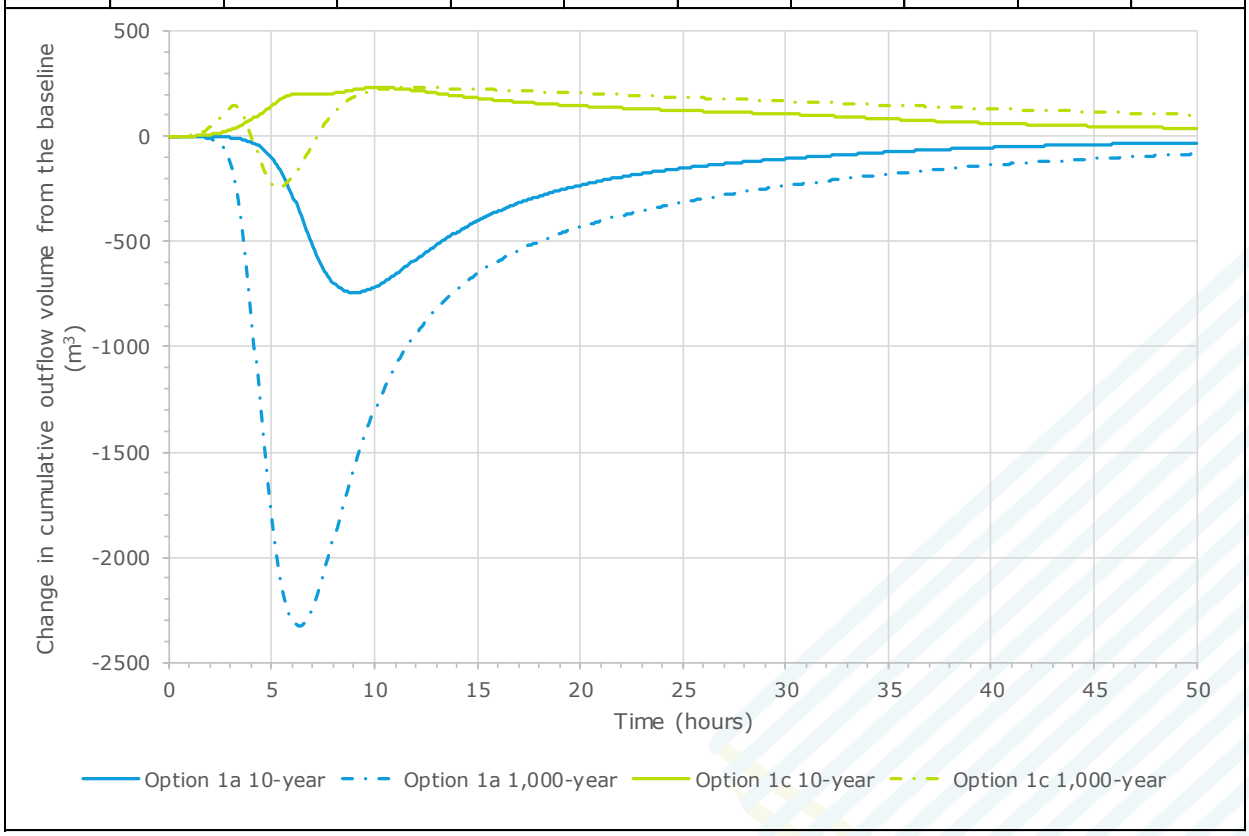


Figure 3-2 Reservoir outflow under the three dam conditions, with baseline optimal storm durations adopted throughout

- Although the total outflow volume remains unchanged, there are incremental differences over the first 50 hours or so of an event, between the three dam conditions (Table 3-2). For example, over the first five hours of a 10-year event, the outflow volume under Option 1a is 41 per cent lower than in the baseline case. In contrast, under Option 1c, the outflow volume over the same period is 58 per cent greater than in the baseline case. These differences diminish to zero as the flood hydrograph moves out of the reservoir.

Table 3-2 Percentage change in cumulative reservoir outflow volume compared to the baseline case

Time (hours)	Option 1a					Option 1c				
	Return period (years)					Return period (years)				
	10	30	100 + CC	1,000	1,000 FSR/FEH	10	30	100 + CC	1,000	1,000 FSR/FEH
5	-41%	-47%	-57%	-57%	-31%	58%	38%	-1%	-7%	4%
10	-29%	-27%	-21%	-18%	-11%	9%	6%	3%	3%	4%
15	-13%	-11%	-8%	-8%	-5%	6%	4%	3%	3%	3%
20	-7%	-6%	-5%	-5%	-3%	4%	3%	2%	2%	2%
50	-1%	-1%	-1%	-1%	0%	1%	1%	1%	1%	2%



- With the exception of Option 1c in a 10-year event, both of the future options lead to a slight increase in the time it takes for the reservoir outflow to reach its peak, compared to the baseline case (Figure 3-2). For example, with the ReFH2 inflows and baseline optimal storm durations adopted throughout, the peak reservoir outflow occurs 0.9 to 1.4 hours later under Option 1a and up to 0.4 hours later under Option 1c. The effect is more marked under Option 1a due to the greater flow restriction that this option poses at the reservoir exit. In a 10-year event, the larger volume of water released on the rising limb under Option 1c compared to the baseline case results in a slightly earlier (5 minutes) peak outflow. At higher return periods, the outflow volume is still higher under Option 1c than in the baseline case for part of the rising limb, but the effect is then counteracted as the reservoir level rises further and overflowing of the dam is prevented unlike in the baseline case.

This leads to the very slight delays reported in the occurrence of peak outflow under Option 1c at return periods of 30-years and longer.

- Predicted peak reservoir levels under each dam condition are given in Table 3-3. In order to achieve a minimum freeboard of 600 mm, the North-East dam should have a top of dam elevation of 306.431 m AOD under Option 1a and 306.304 m AOD under Option 1c.
- It is worth noting that the future options afford a minimum freeboard of 818 mm at the West dam (based on an existing minimum dam crest level of 306.649 m AOD).
- The FSR/FEH hydrology gives a higher 1,000-year peak stillwater level than the ReFH2 hydrology in the baseline case and Option 1c, but a lower level in Option 1a. This is due to the fact that Option 1a poses a greater restriction to reservoir outflow than the other dam conditions and is, consequently, more sensitive to the volume of water entering the reservoir. Since the 1,000-year ReFH2 inflow hydrograph has a greater flow volume than the FSR/FEH hydrograph, it generates a higher peak stillwater level under Option 1a, despite having a lower peak flow.
- This sensitivity to inflow volume also explains why the optimal storm durations are much longer under Option 1a compared to the other dam conditions.
- To assess whether the flood risk impacts of the future options vary with storm duration, peak reservoir outflow has been compared against downstream peak fluvial inflow at PenNE01 for the full range of optimal storm durations identified in Table 2-1. The results show that the reduction in peak outflow afforded by the future options, compared to the baseline case, remains a fairly constant percentage of the downstream peak fluvial inflow (2-3% in the case of Option 1a and 0-1% for Option 1c, based on ReFH2; 5% and 1%, respectively, based on FSR/FEH). Given that there is little variation in the size of the peak flow impact with storm duration, use of the baseline optimal storm durations in all RFM model runs is considered justified. This reduces the total number of RFM model runs required from 45 to 15.

Table 3-3 Maximum stillwater flood level predictions (m AOD)

Dam condition	Return period (years)						Proposed dam height (m AOD)
	10	30	100 + CC	1,000	1,000 FSR/FEH	100 + CC 50% blockage	
Baseline	305.607	305.620	305.648	305.660	305.681	n/a	n/a
Option 1a	305.661	305.695	305.789	305.831	305.804	306.234	306.431
Option 1c	305.590	305.608	305.654	305.676	305.704	306.047	306.304

- The RFM model results, presented in Appendix B, show that the future options generally have either a neutral or slightly beneficial impact on downstream flood risk, compared to the baseline case. (A depth difference of less than 5 mm has been taken to represent zero change, in line with NRW guidance (2018).)
- An exception occurs around the first track crossing, where there is a very localised increase in flood risk. Maximum 1,000-year flood depths here are generally 10 to 70 mm higher under the future options than in the baseline case, although larger increases of 100 to 550 mm occur in a limited area immediately upstream of the track. Velocities are also higher, typically by 0.1 to 0.3 m s^{-1}. The effects are slightly worse under Option 1c than Option 1a.
- This localised increase in flood risk is due to the change in position of reservoir outflow between the baseline case and the future options. As mentioned in Section 2.3, the baseline outflow hydrographs have been entered into the RFM model at the right-hand end of the dam. There is, consequently, some attenuation of the outflow before it reaches the first track crossing. In the future options, this attenuation is lost since the outflow hydrographs have been entered into the RFM model immediately upstream of the track crossing. The loss of flood attenuation is

demonstrated by the flood extent difference maps in Appendix B (drawing nos. 16, 19, 22 and 25).

- Flood extent around the B5106 road culvert is also sensitive, over a very small area, to the differences between the three dam conditions. The sensitivity is most noticeable in a 10-year event, when flooding of the road is marginal and flood depths are very shallow. During this event, the reduction in reservoir outflow under Option 1a leads to a slight decrease in flood extent, compared to the baseline case (Appendix B, drawing no. 16). In contrast, under Option 1c, there is a slight increase in flood extent (Appendix B, drawing no. 19), which can be attributed to the greater reservoir outflow volume on the rising limb. At longer return periods, flood extent in this location exhibits less sensitivity to dam condition (Appendix B, drawing nos. 22 and 25).
- Away from the first track crossing and the B5106, the future options either have a negligible effect or slightly reduce downstream flood risk. Maximum 1,000-year flood depths along the flow thalweg and its margins are typically 5 to 30 mm lower under Options 1a and 1c than in the baseline case, while flow velocities are reduced generally by 0.1 m s^{-1} or less. Option 1a affords slightly greater and more extensive reductions than Option 1c. Outside of the flow thalweg, the flood risk remains largely the same between the baseline case and the future options.
- Whilst Option 1a affords some reduction in downstream flood risk at all of the return periods considered, Option 1c provides little or no risk reduction during the 10, 30 and 100-year + CC events.
- Under all three dam conditions, flooding is predicted to affect the mine spoil heaps, located downstream of Pen Y Gwaith (Upper & Lower). There is, consequently, potential for mobilisation and transport of metal-contaminated sediment, including during the relatively frequent 10-year flood event. This poses a risk to ecological health, particularly aquatic life.
- As mentioned in Section 1.2, the spoil heaps form part of the Gwydyr Forest Mines SSSI. In the baseline case, the average maximum 10-year flood depths and flow velocities within this SSSI are 100 mm and 0.3 m s^{-1}, respectively. These average values rise to 140 mm and 0.5 m s^{-1}, respectively, in the 1,000-year event, based on the ReFH2 hydrology, with maximum values of 2.6 m and 3.6 m s^{-1}.
- Both of the future options lead to a very slight reduction in flood risk over parts of the mine spoil heaps, in a 1,000-year event at least, compared to the baseline case. However, it is important to bear in mind that the predicted flooding is not caused solely by reservoir outflow. There is also a downstream fluvial component, associated with runoff from the lateral catchment of the outflowing stream. The potential for flood-related contaminant mobilisation, therefore, exists, irrespective of whether Pen Y Gwaith (Upper & Lower) is properly maintained, discontinued or abandoned.
- The environmental risks associated with the spoil heaps in Gwydyr Forest were realised in 1964, when a storm event caused the west slope of the tailings dam at Parc mine (Figure 1-1) to collapse into the river, polluting 11 ha of farmland with lead and zinc. The resulting toxicity in cereals led to cattle deaths (Davies *et al*, 2015). Reclamation work commenced in 1978 and involved reshaping and stabilising the tailings with limestone quarry waste and metal-tolerant vegetation.
- 50 per cent blockage of the spillway at Pen Y Gwaith (Upper & Lower), during a 100-year + CC event, does not lead to overflowing of the dam in either of the future options (Table 3-3). Freeboards of 197 and 257 mm are maintained under Options 1a and 1c, respectively.

4 Conclusion and recommendations

This FCA has been undertaken to assess the flood risk impacts of two future remedial options for Pen Y Gwaith (Upper & Lower) North-East dam. The following conclusions can be drawn from the study:

- For the most part, the future remedial options being considered by NRW either have a negligible effect or slightly reduce downstream flood risk.
- Option 1a (1.32 m wide spillway) decreases peak reservoir outflow typically by around one-third, compared to the baseline case, and affords more extensive reductions in downstream flood risk than Option 1c (5.0 m wide spillway).
- Option 1c decreases peak reservoir outflow by less than 10 per cent, compared to the baseline case.
- The total volume of reservoir outflow remains unchanged between the baseline case and the future options, since the same spillway invert elevation (305.513 m AOD) is used throughout.
- The future options do result in changes to the incremental outflow volume over the first 50 hours or so of an event. During this time period, the outflow volume is consistently lower under Option 1a than in the baseline case and partially higher (both sides of the flood peak) under Option 1c.
- The time-limited increases in outflow volume under Option 1c do not have a significant adverse effect on downstream flood risk. The RFM results indicate that this risk is more sensitive to peak flow than flood volume.
- During a 1,000-year event, the reductions in peak reservoir outflow, provided by the future options, lead generally to small decreases in flood risk along the outflow channel and its margins, compared to the baseline case. Maximum flood depths and flow velocities are reduced typically by 5-30 mm and ≤0.1 m s^{-1}, respectively. On the floodplain, away from the flow thalweg, there is little or no change in flood risk.
- Whilst Option 1a affords some reduction in downstream flood risk at all of the return periods considered, Option 1c only provides noticeable risk reduction during the 1,000-year event.
- An exception to the neutral or beneficial effect occurs around the first track crossing downstream of the North-East dam. Here, both of the future options cause a very localised increase in flood risk. This increase is due to the change in position of reservoir outflow, between the baseline case and the future options, and the associated loss of flood attenuation. It is important to bear in mind that there is limited channel definition in the DTM upstream of the track crossing, which may contribute to the effects shown. The increase in flood risk is considered manageable but should be considered further at the detailed design stage. In particular, NRW may wish to refine the RFM model in this location, adding more topographic detail, as part of the design optimisation of the preferred option.
- Flood extents around the B5106 road culvert are also sensitive, over a very small area, to the differences between the three dam conditions. The effect, which is most noticeable in a 10-year event, is slight, however, and not considered to pose a constraint to the proposed works. To allay any concerns, the RFM model could again be refined at the detailed design stage and run for shorter return periods (e.g. 2 and 5-year).
- In order to achieve a minimum reservoir freeboard of 600 mm, the North-East dam should have a top of dam elevation of 306.431 m AOD under Option 1a and 306.304 m AOD under Option 1c.
- In the event of a 50 per cent blockage of the spillway during a 100-year + CC event, overflowing of the North-East dam is not predicted to occur under either Option 1a or 1c.

- Whilst Option 1c affords a less extensive reduction in downstream flood risk than Option 1a under normal conditions, its wider spillway has a lower probability of blocking.
- Under existing baseline conditions, the mine spoil heaps, located downstream of Pen Y Gwaith (Upper & Lower), are at risk of flooding during relatively frequent events. There is, consequently, potential for mobilisation and transport of metal-contaminated sediment, which poses a risk to ecological health. The future options reduce this potential only very slightly.
- NRW is acutely aware of the environmental risks posed by flood-related mobilisation of heavy metals from spoil heaps in Gwydyr Forest and is continuing to work to reduce these risks. A field-based investigation of the impact of short-lived flood events on the release of metals from the Gwydyr mine spoil heaps into the water column would be beneficial for informing the development of a risk management strategy, including remediation measures where necessary.

5 References

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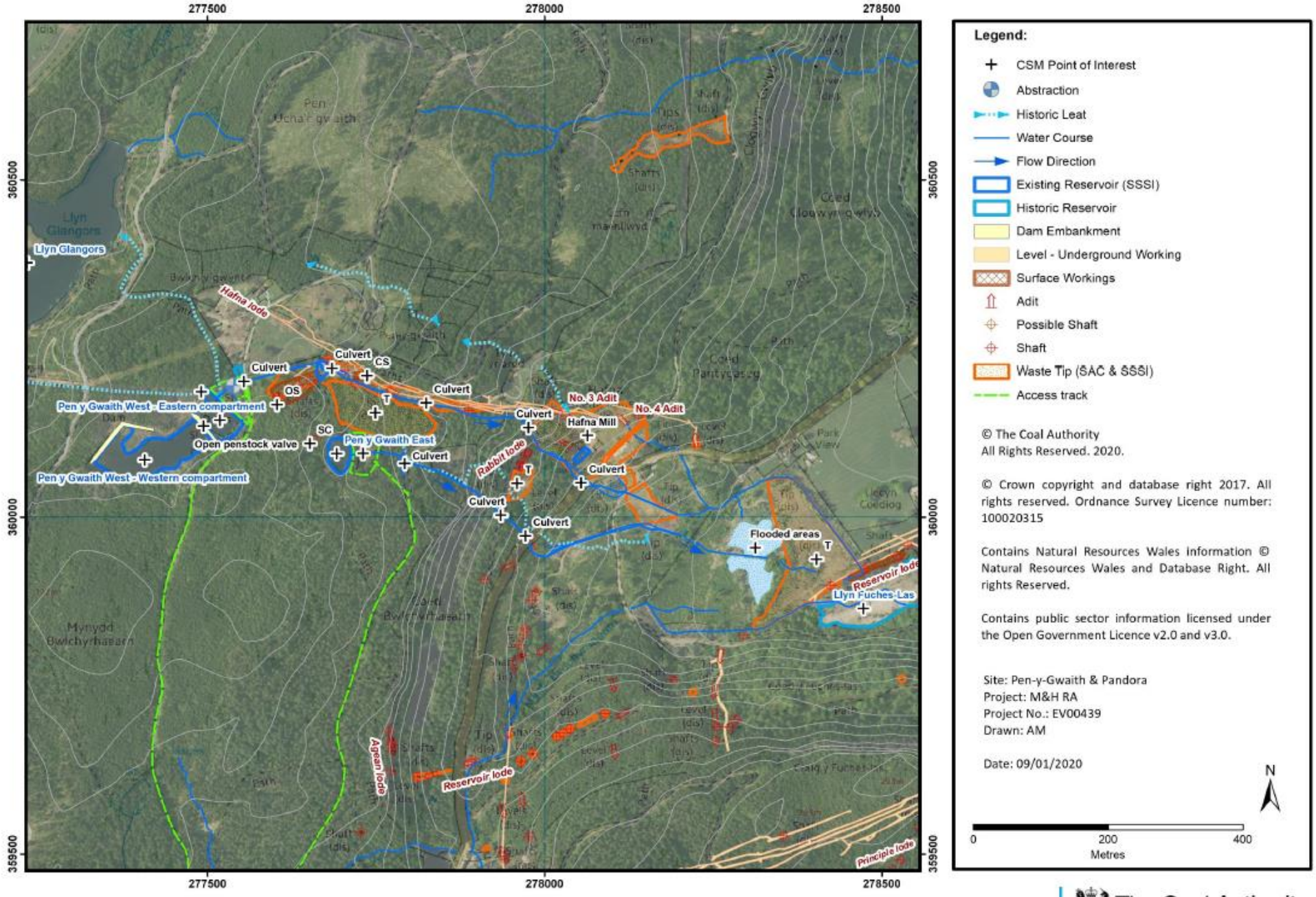
Appendix A – Mining and drainage features identified by the Coal Authority



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The Coal Authority

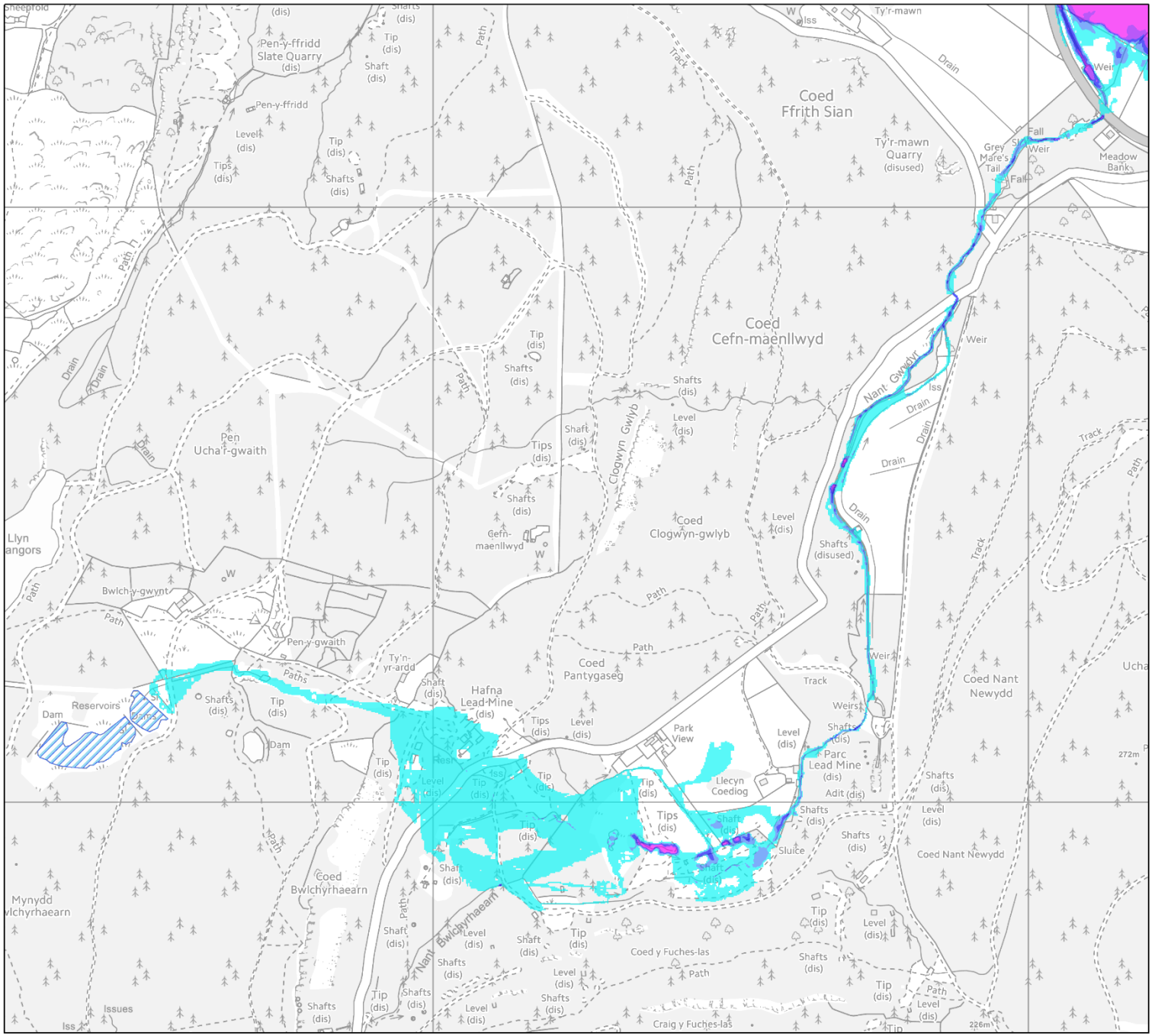
Appendix B – RFM outputs

The drawings contained within this Appendix are listed below:

Drawing no.	Dam condition	Return period	Parameter
01	Baseline	10-year	Flood depth
02	Baseline	10-year	Velocity
03	Baseline	10-year	Hazard rating
04	Baseline	30-year	Flood depth
05	Baseline	30-year	Velocity
06	Baseline	30-year	Hazard rating
07	Baseline	100-year + CC	Flood depth
08	Baseline	100-year + CC	Velocity
09	Baseline	100-year + CC	Hazard rating
10	Baseline	1,000-year	Flood depth
11	Baseline	1,000-year	Velocity
12	Baseline	1,000-year	Hazard rating
13	Baseline	1,000-year FSR/FEH	Flood depth
14	Baseline	1,000-year FSR/FEH	Velocity
15	Baseline	1,000-year FSR/FEH	Hazard rating
16	Option 1a versus Baseline	10-year	Flood extent difference
17	Option 1a minus Baseline	10-year	Depth difference
18	Option 1a minus Baseline	10-year	Velocity difference
19	Option 1a versus Baseline	1,000-year	Flood extent difference
20	Option 1a minus Baseline	1,000-year	Depth difference
21	Option 1a minus Baseline	1,000-year	Velocity difference
22	Option 1c versus Baseline	10-year	Flood extent difference
23	Option 1c minus Baseline	10-year	Depth difference
24	Option 1c minus Baseline	10-year	Velocity difference
25	Option 1c versus Baseline	1,000-year FSR/FEH	Flood extent difference
26	Option 1c minus Baseline	1,000-year FSR/FEH	Depth difference
27	Option 1c minus Baseline	1,000-year FSR/FEH	Velocity difference

Drawing no. 001

Return to list of drawings



Reservoir extent marker

Flood depth (m):

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.2
- > 1.2

0 50 100 200 Metres

Information Warning:
This map gives an indication of the areas that may be flooded during a fluvial flood event, taking account of reservoir outflow. It is based on a simplified modelling approach and is intended for strategic flood risk assessment purposes only.

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Natural Resources Wales

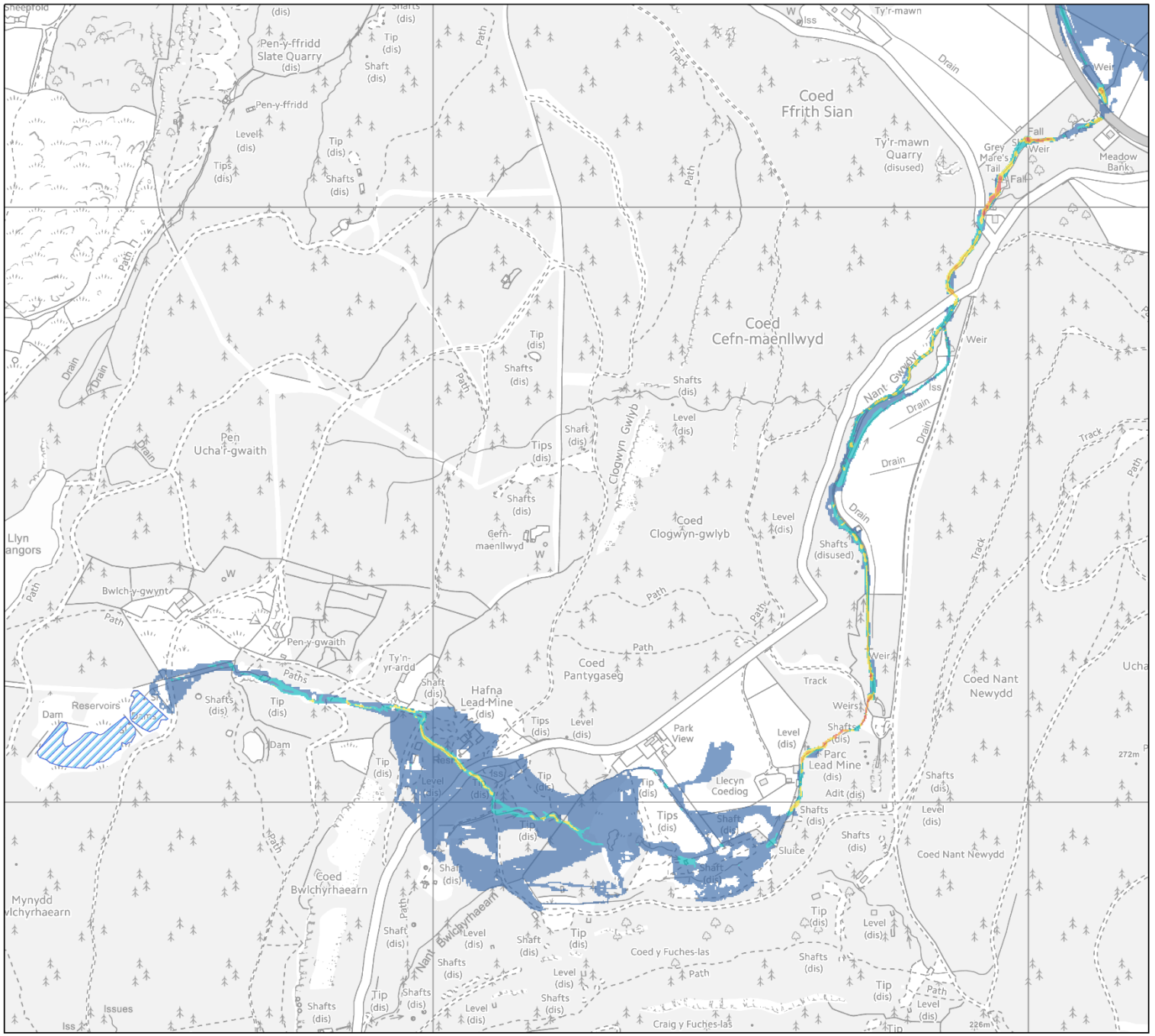
Predicted flood depths
Baseline 10-year event

Scale: 1:6,000	Drawn	CF
	Checked	CS
Original @ A3	Approved	CS

Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_001	Sheet No: 1 of 1	Status: Final	Rev: A

Drawing no. 002

Return to list of drawings



Reservoir extent marker

Velocity (m/s):

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- > 2.0

0 50 100 200 Metres

Information Warning:
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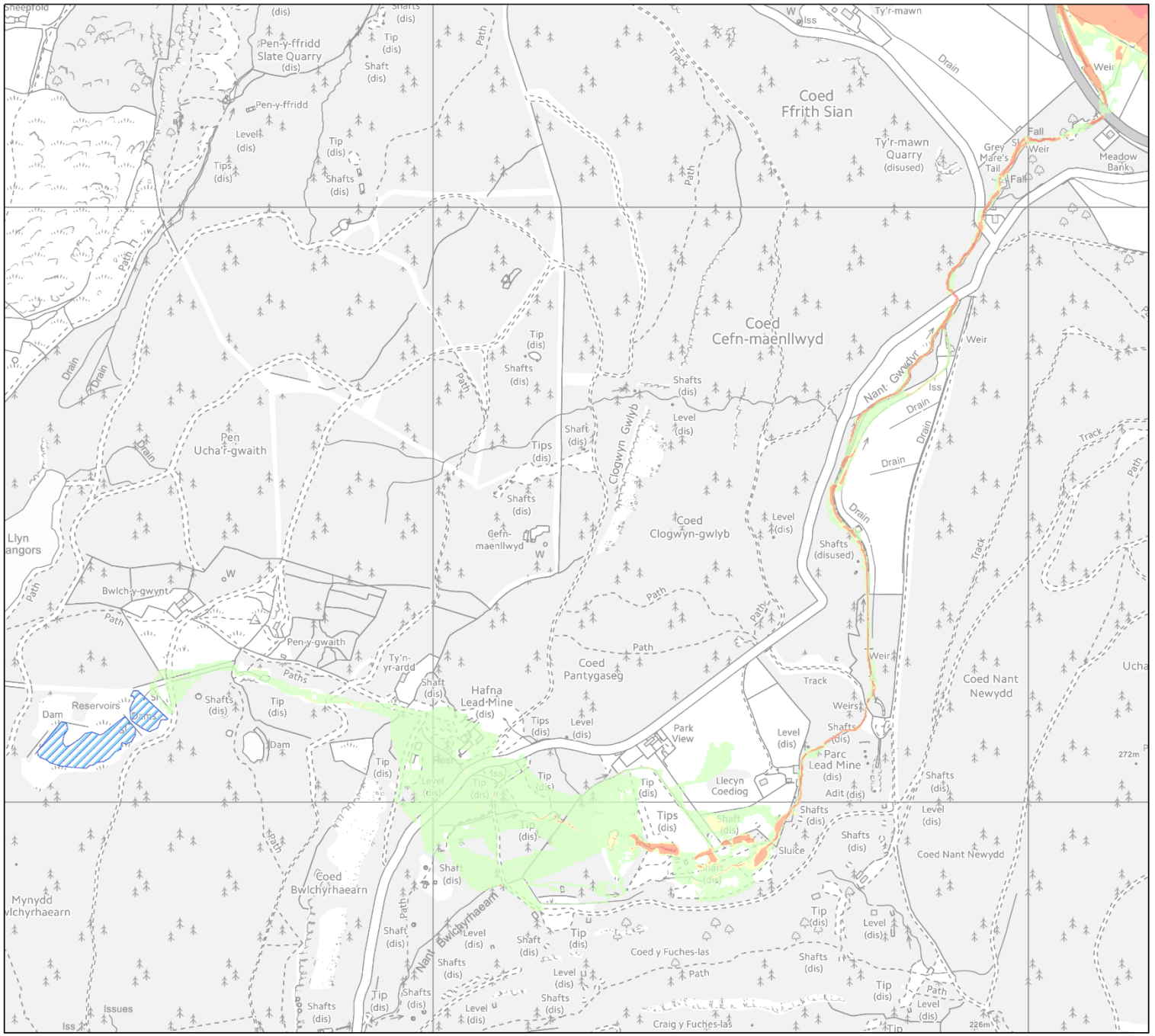
Maximum velocity
Baseline 10-year event

Scale: 1:6,000	Drawn	CF
	Checked	CS
Original @ A3	Approved	CS

Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_002	Sheet No: 1 of 1	Status: Final	Rev: A

Drawing no. 003

Return to list of drawings



Reservoir extent marker

Hazard Rating:

- < 0.75 (Very low hazard)
- 0.75 - 1.25 (Danger for some)
- 1.25 - 2.0 (Danger for most)
- > 2.0 (Danger for all)

0 50 100 200 Metres

Information Warning:
This map gives an indication of the areas that may be flooded during a fluvial flood event, taking account of reservoir outflow. It is based on a simplified modelling approach and is intended for strategic flood risk assessment purposes only.

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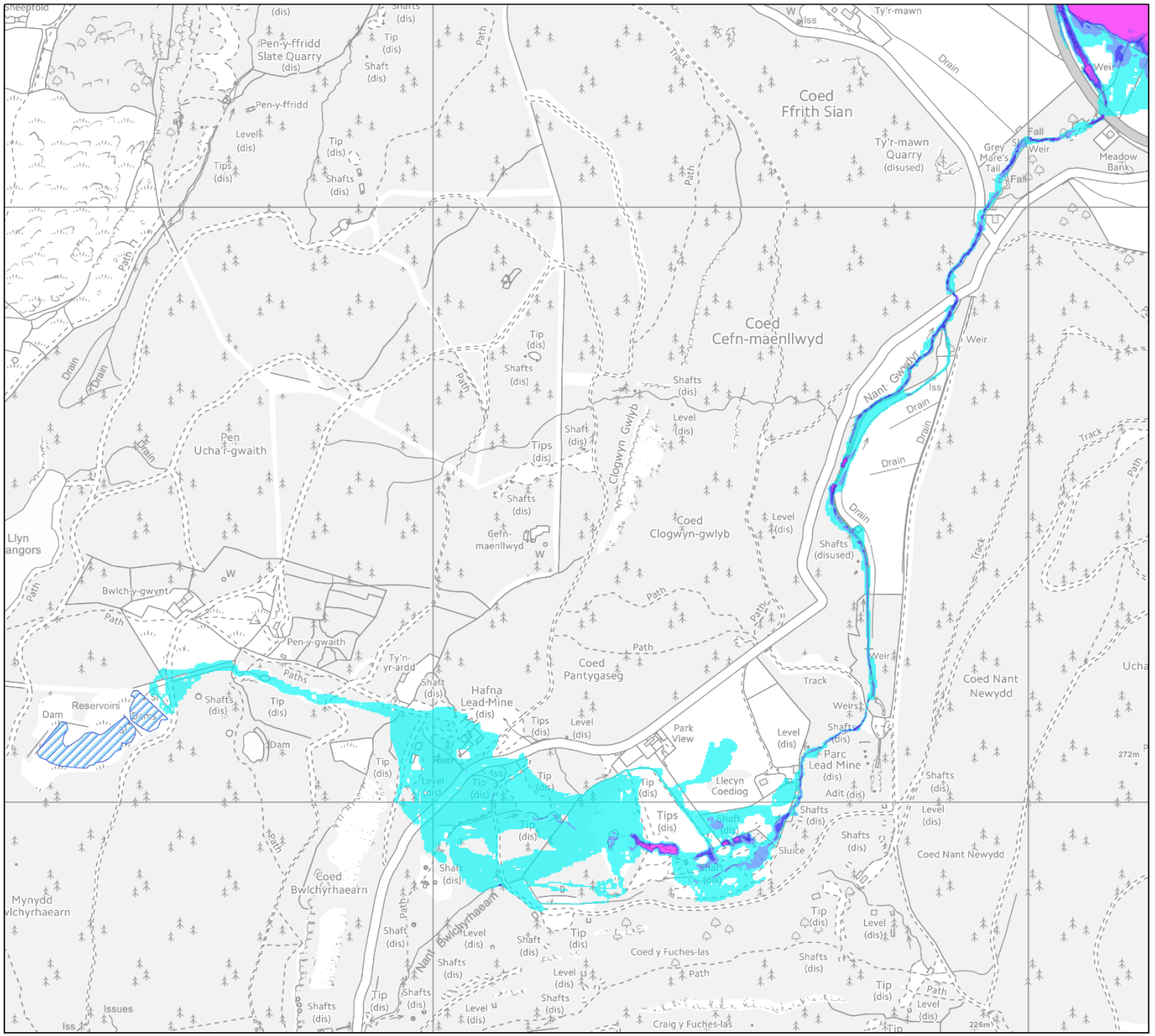
Hazard Rating
Baseline 10-year event

Scale: 1:6,000	Drawn	CF
	Checked	CS
Original @ A3	Approved	CS

Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_003	Sheet No: 1 of 1	Status: Final	Rev: A

Drawing no. 004

Return to list of drawings



Reservoir extent marker

Flood depth (m):

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.2
- > 1.2

0 50 100 200 Metres

Information Warning:
This map gives an indication of the areas that may be flooded during a fluvial flood event, taking account of reservoir outflow. It is based on a simplified modelling approach and is intended for strategic flood risk assessment purposes only.

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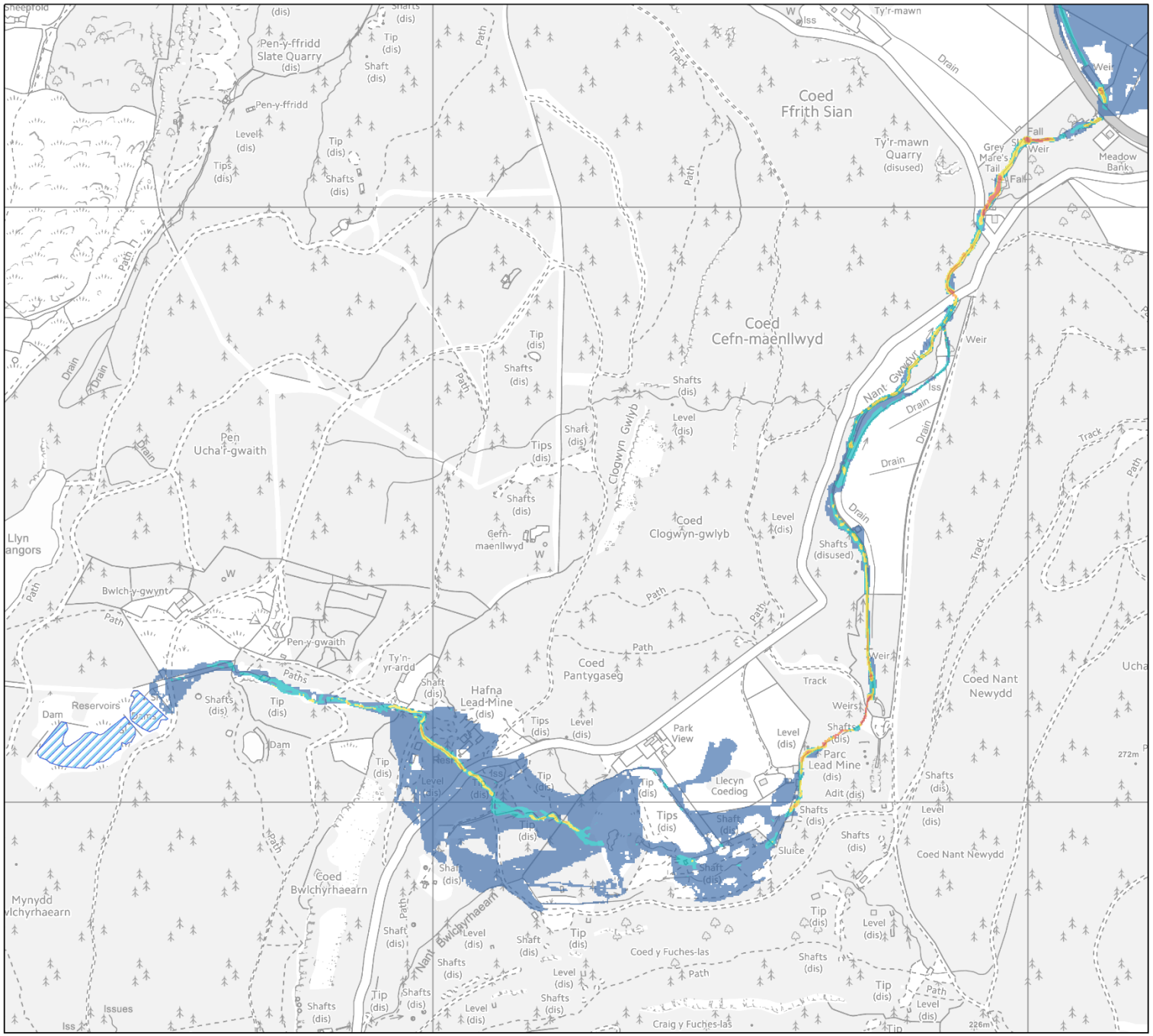
Predicted flood depths
Baseline 30-year event

Scale: 1:6,000	Drawn	CF
	Checked	CS
Original @ A3	Approved	CS

Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_004	Sheet No: 1 of 1	Status: Final	Rev: A

Drawing no. 005

Return to list of drawings



Reservoir extent marker

Velocity (m/s):

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- > 2.0

0 50 100 200 Metres

Information Warning:
This map gives an indication of the areas that may be flooded during a fluvial flood event, taking account of reservoir outflow. It is based on a simplified modelling approach and is intended for strategic flood risk assessment purposes only.

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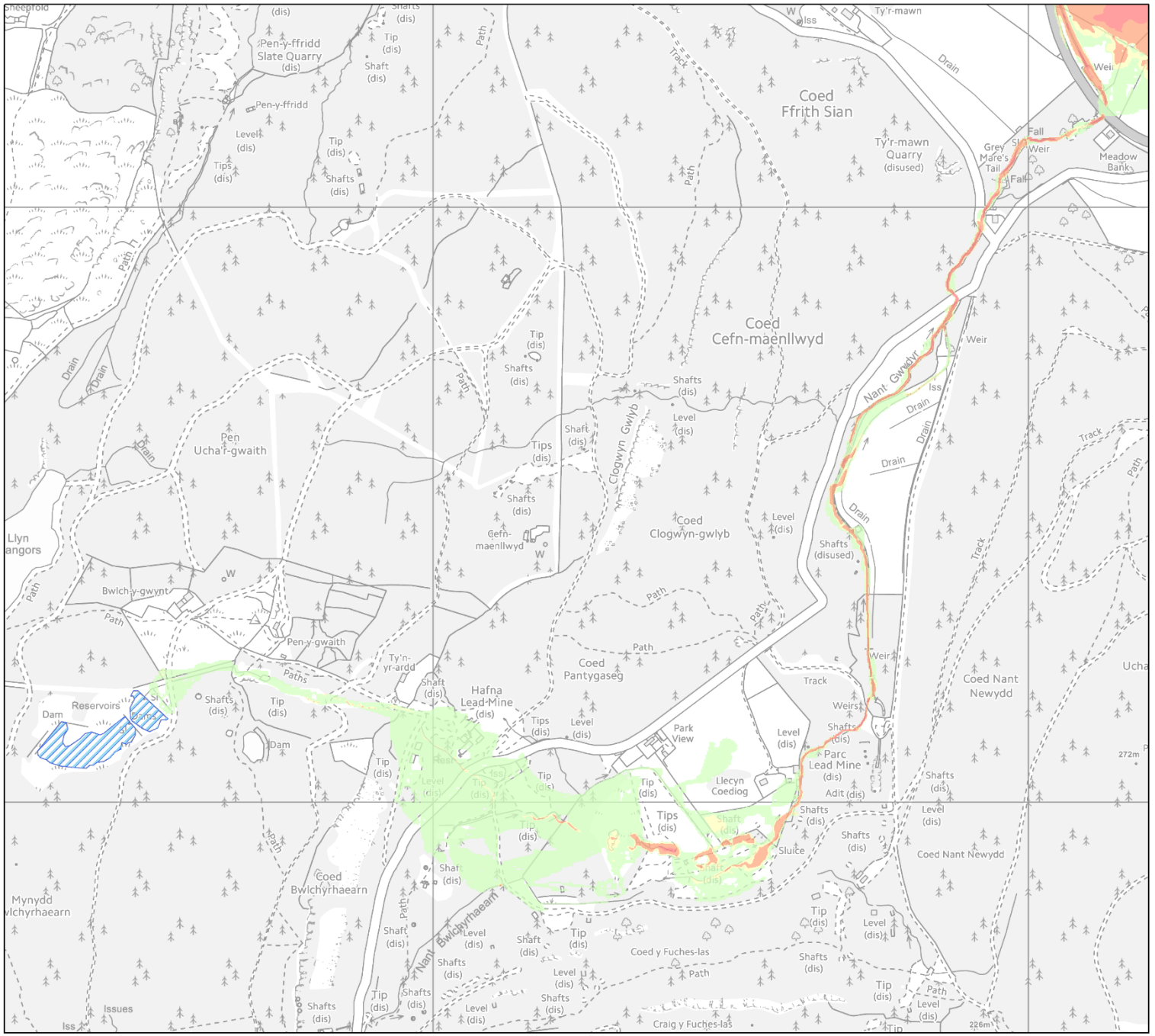
Maximum velocity
Baseline 30-year event

Scale: 1:6,000	Drawn	CF
	Checked	CS
Original @ A3	Approved	CS

Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_005	Sheet No: 1 of 1	Status: Final	Rev: A

Drawing no. 006

Return to list of drawings



Reservoir extent marker

Hazard Rating:

- < 0.75 (Very low hazard)
- 0.75 - 1.25 (Danger for some)
- 1.25 - 2.0 (Danger for most)
- > 2.0 (Danger for all)

0 50 100 200 Metres

Information Warning:
This map gives an indication of the areas that may be flooded during a fluvial flood event, taking account of reservoir outflow. It is based on a simplified modelling approach and is intended for strategic flood risk assessment purposes only.

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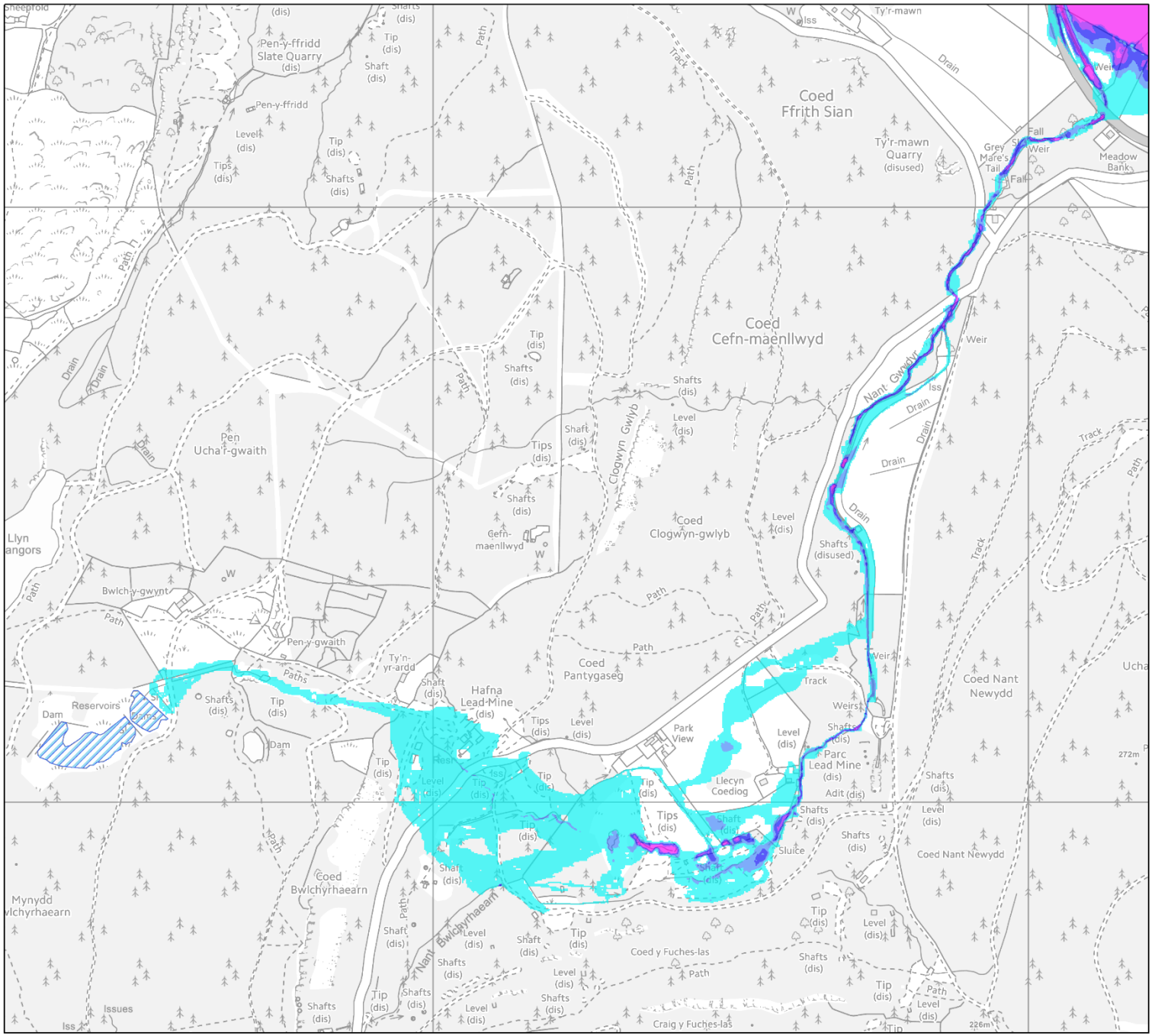
Hazard Rating
Baseline 30-year event

Scale: 1:6,000	Drawn	CF
	Checked	CS
Original @ A3	Approved	CS

Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_006	Sheet No: 1 of 1	Status: Final	Rev: A

Drawing no. 007

Return to list of drawings



Reservoir extent marker

Flood depth (m):

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.2
- > 1.2

0 50 100 200 Metres

Information Warning:
This map gives an indication of the areas that may be flooded during a fluvial flood event, taking account of reservoir outflow. It is based on a simplified modelling approach and is intended for strategic flood risk assessment purposes only.

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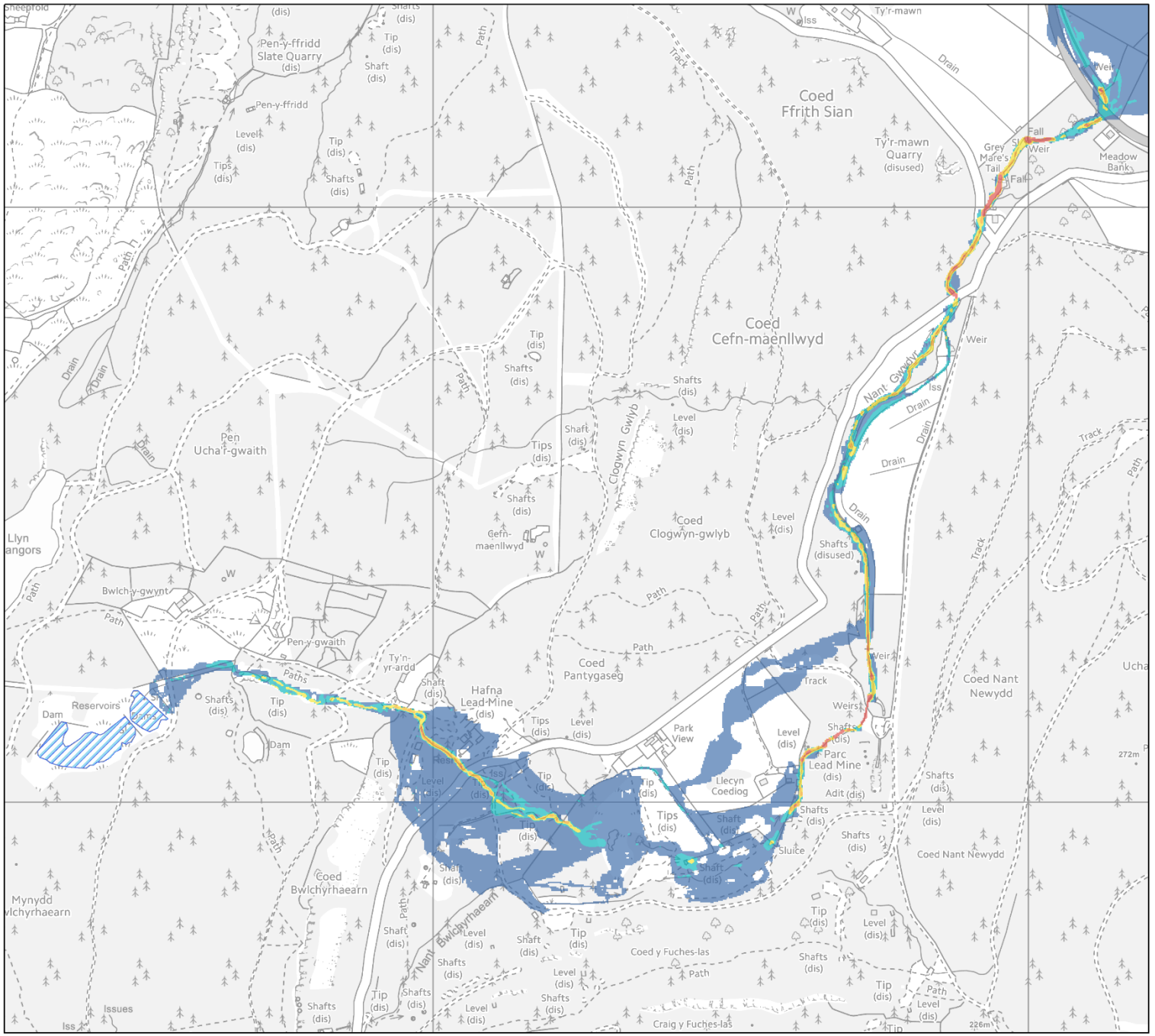
Predicted flood depths
Baseline 100-year + CC event

Scale: 1:6,000	Drawn	CF	
	Checked	CS	
Original @ A3	Approved	CS	
Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_007	Sheet No: 1 of 1	Status: Final	Rev: A

Drawing no. 008

Return to list of drawings



Reservoir extent marker

Velocity (m/s):

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- > 2.0

0 50 100 200 Metres

Information Warning:
This map gives an indication of the areas that may be flooded during a fluvial flood event, taking account of reservoir outflow. It is based on a simplified modelling approach and is intended for strategic flood risk assessment purposes only.

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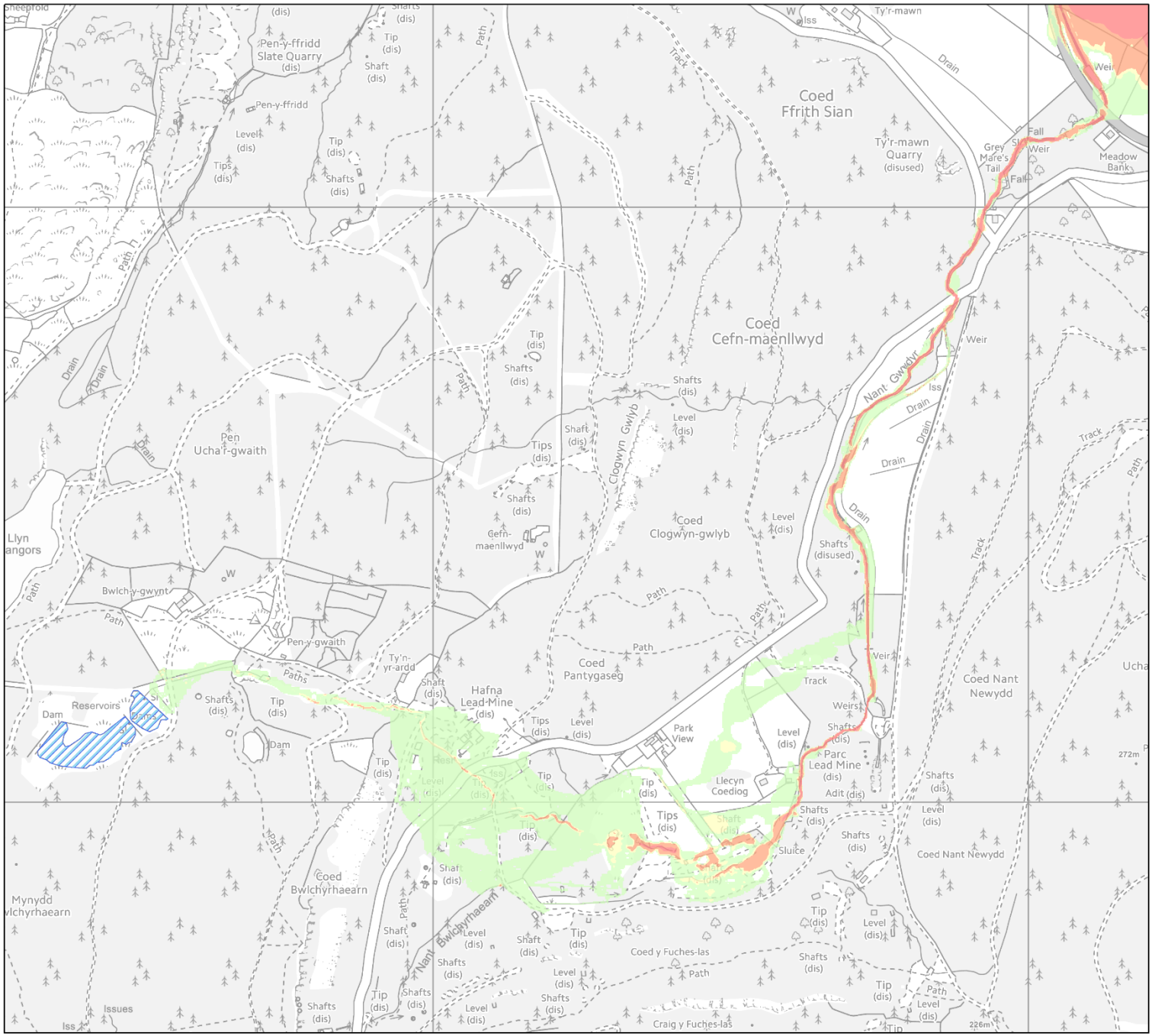
Maximum velocity
Baseline 100-year + CC event

Scale: 1:6,000	Drawn	CF
	Checked	CS
Original @ A3	Approved	CS

Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_008	Sheet No: 1 of 1	Status: Final	Rev: A

Drawing no. 009

Return to list of drawings



Reservoir extent marker

Hazard Rating:

- < 0.75 (Very low hazard)
- 0.75 - 1.25 (Danger for some)
- 1.25 - 2.0 (Danger for most)
- > 2.0 (Danger for all)

0 50 100 200 Metres

Information Warning:
This map gives an indication of the areas that may be flooded during a fluvial flood event, taking account of reservoir outflow. It is based on a simplified modelling approach and is intended for strategic flood risk assessment purposes only.

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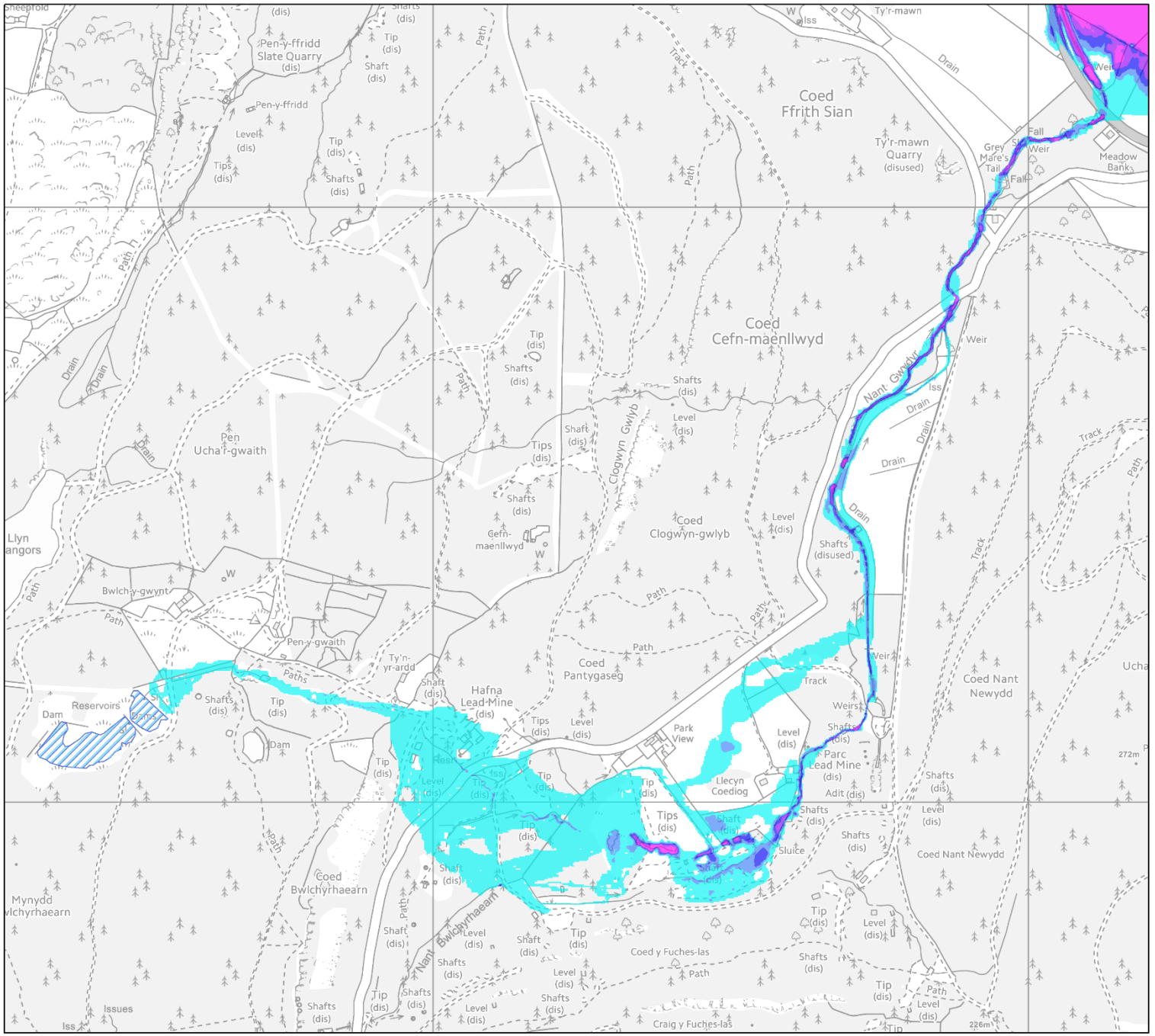
Hazard Rating
Baseline 100-year + CC event

Scale: 1:6,000	Drawn	CF
	Checked	CS
Original @ A3	Approved	CS

Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_009	Sheet No: 1 of 1	Status: Final	Rev: A

Drawing no. 010

Return to list of drawings



Reservoir extent marker

Flood depth (m):

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.2
- > 1.2

0 50 100 200 Metres

Information Warning:
This map gives an indication of the areas that may be flooded during a fluvial flood event, taking account of reservoir outflow. It is based on a simplified modelling approach and is intended for strategic flood risk assessment purposes only.

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Natural Resources Wales

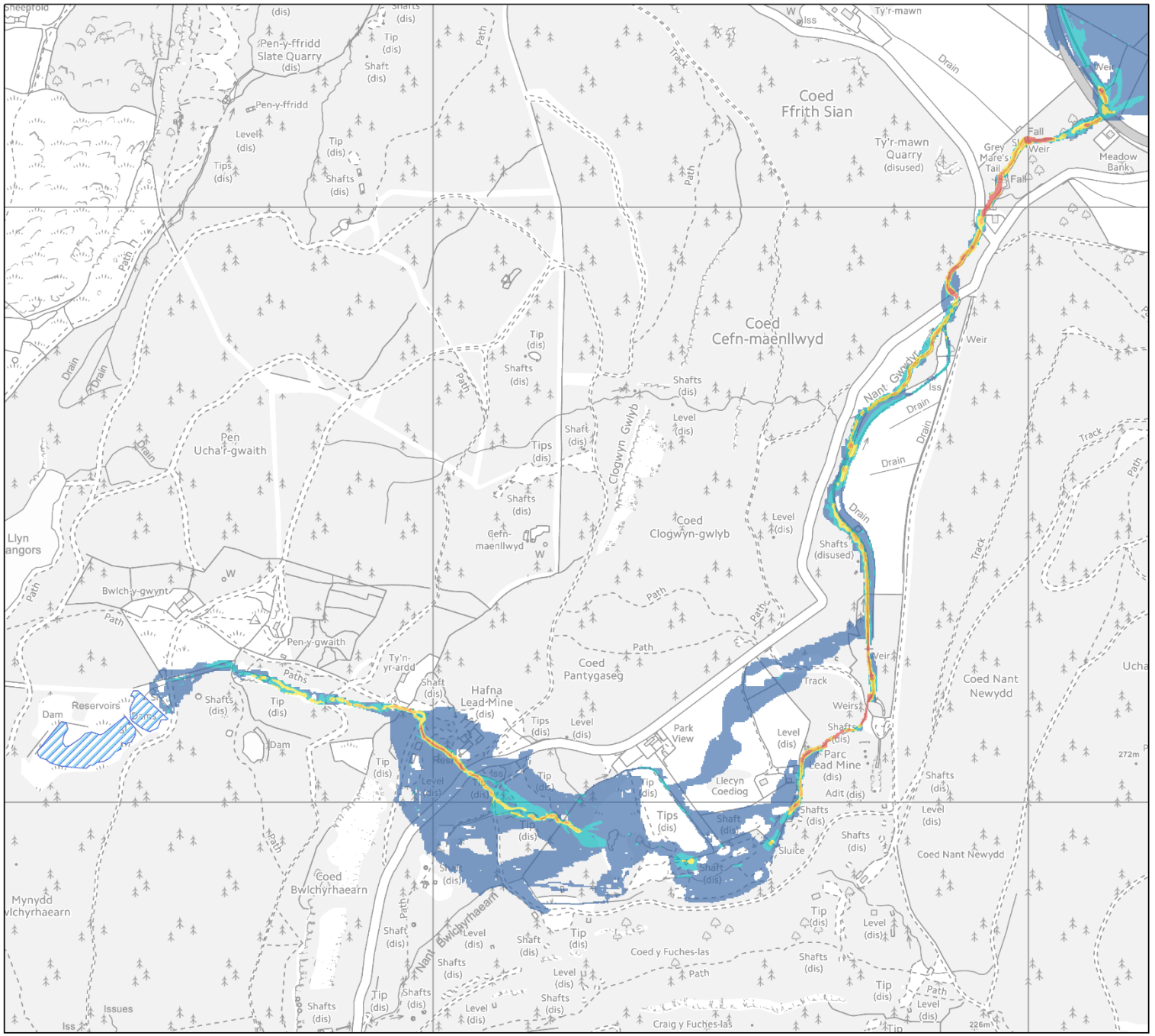
Predicted flood depths
Baseline 1,000-year event

Scale: 1:6,000	Drawn	CF
	Checked	CS
Original @ A3	Approved	CS

Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_010	Sheet No: 1 of 1	Status: Final	Rev: A

Drawing no. 011

Return to list of drawings



Reservoir extent marker

Velocity (m/s):

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- > 2.0

0 50 100 200 Metres

Information Warning:
This map gives an indication of the areas that may be flooded during a fluvial flood event, taking account of reservoir outflow. It is based on a simplified modelling approach and is intended for strategic flood risk assessment purposes only.

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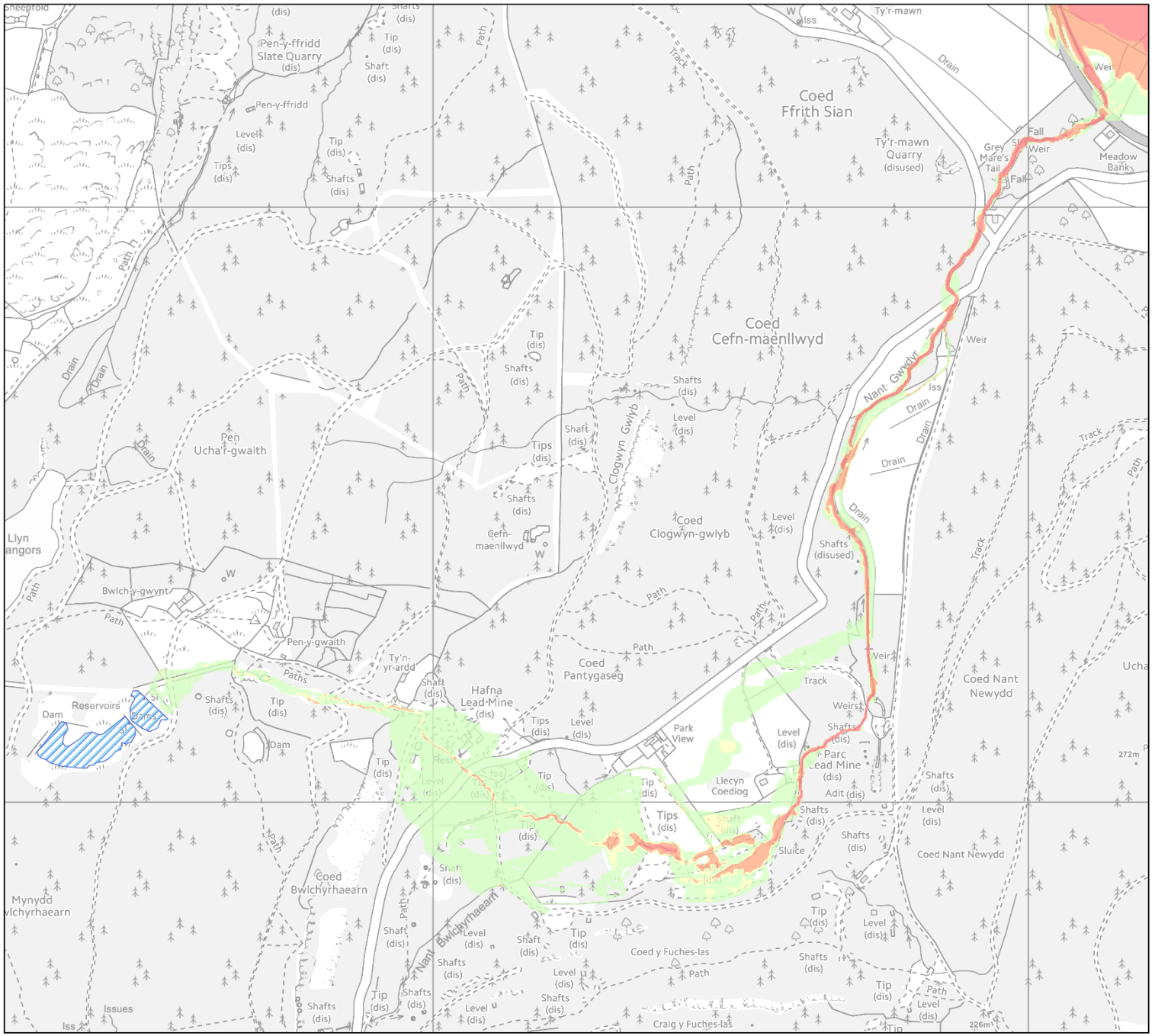
Maximum velocity
Baseline 1,000-year event

Scale: 1:6,000	Drawn	CF
	Checked	CS
Original @ A3	Approved	CS

Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_011	Sheet No: 1 of 1	Status: Final	Rev: A

Drawing no. 012

Return to list of drawings



Reservoir extent marker

Hazard Rating:

- < 0.75 (Very low hazard)
- 0.75 - 1.25 (Danger for some)
- 1.25 - 2.0 (Danger for most)
- > 2.0 (Danger for all)

0 50 100 200 Metres

Information Warning:
This map gives an indication of the areas that may be flooded during a fluvial flood event, taking account of reservoir outflow. It is based on a simplified modelling approach and is intended for strategic flood risk assessment purposes only.

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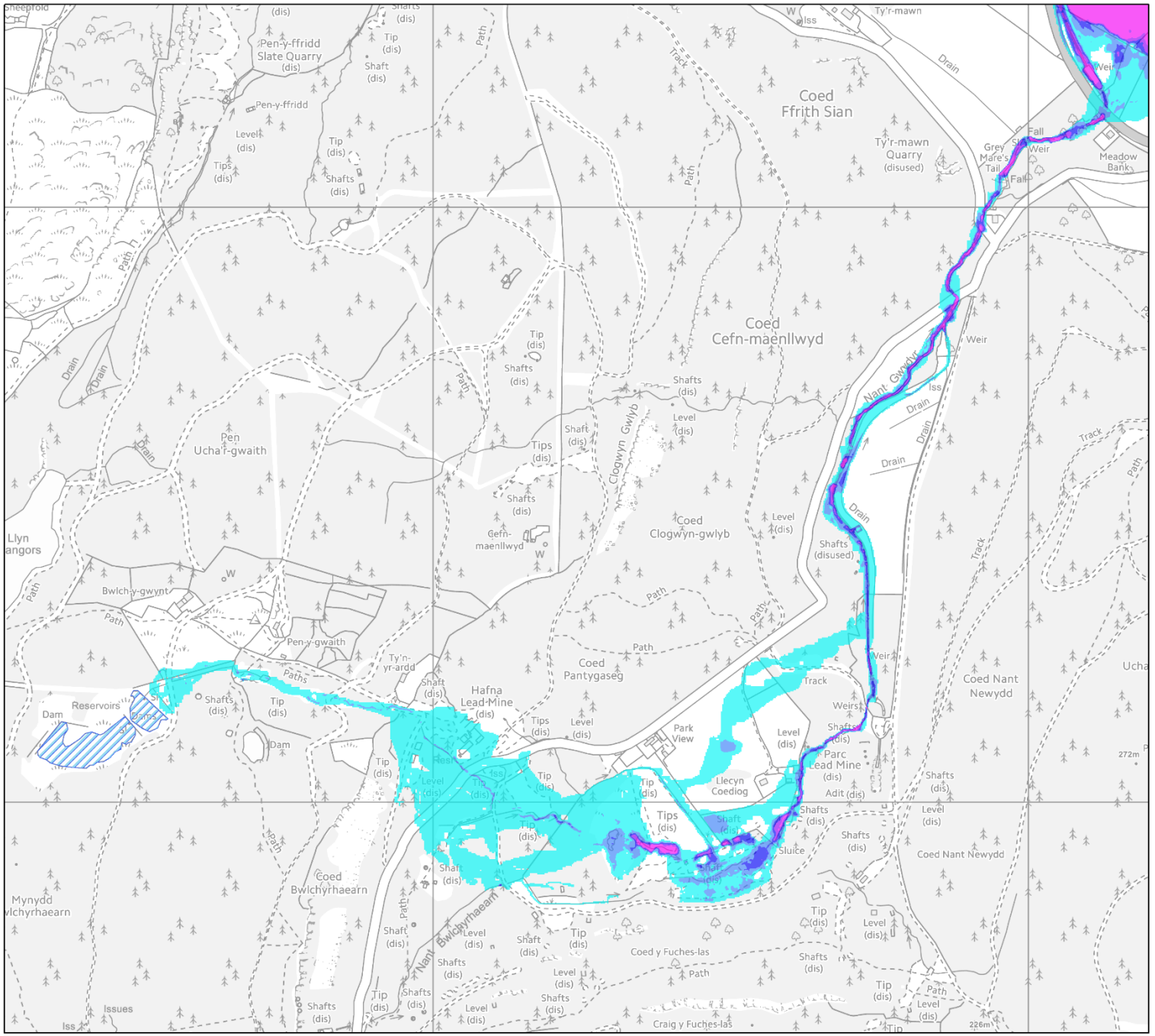
Hazard Rating
Baseline 1,000-year event

Scale: 1:6,000	Drawn	CF
	Checked	CS
Original @ A3	Approved	CS

Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_012	Sheet No: 1 of 1	Status: Final	Rev: A

Drawing no. 013

Return to list of drawings



Reservoir extent marker

Flood depth (m):

- 0.0 - 0.3
- 0.3 - 0.6
- 0.6 - 0.9
- 0.9 - 1.2
- > 1.2

0 50 100 200 Metres

Information Warning:
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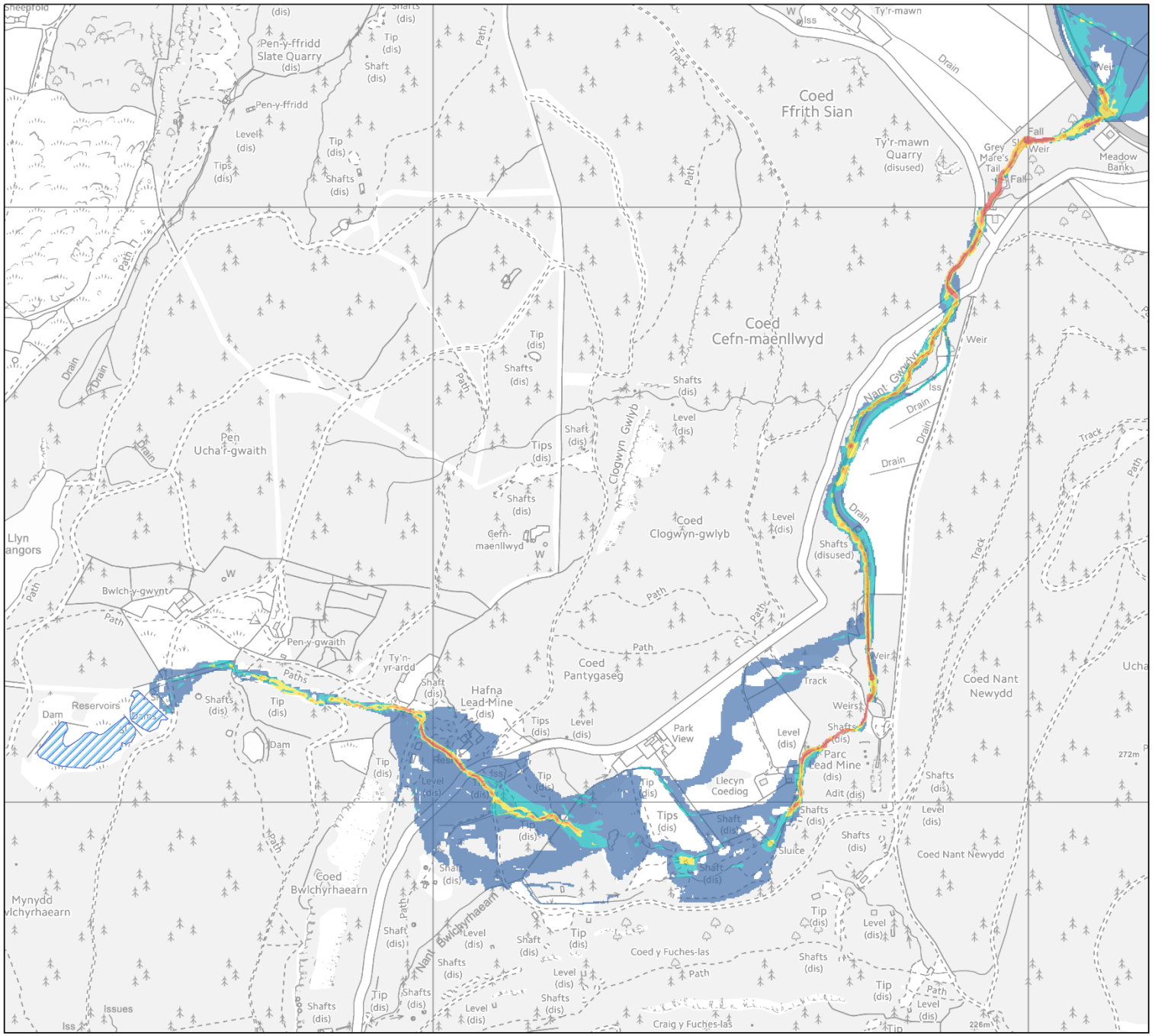
Predicted flood depths
Baseline 1,000-year FSR/FEH event

Scale: 1:6,000	Drawn	CF
	Checked	CS
Original @ A3	Approved	CS

Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_013	Sheet No: 1 of 1	Status: Final	Rev: A

Drawing no. 014

Return to list of drawings



Reservoir extent marker

Velocity (m/s):

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- > 2.0

N

0 50 100 200 Metres

Information Warning:
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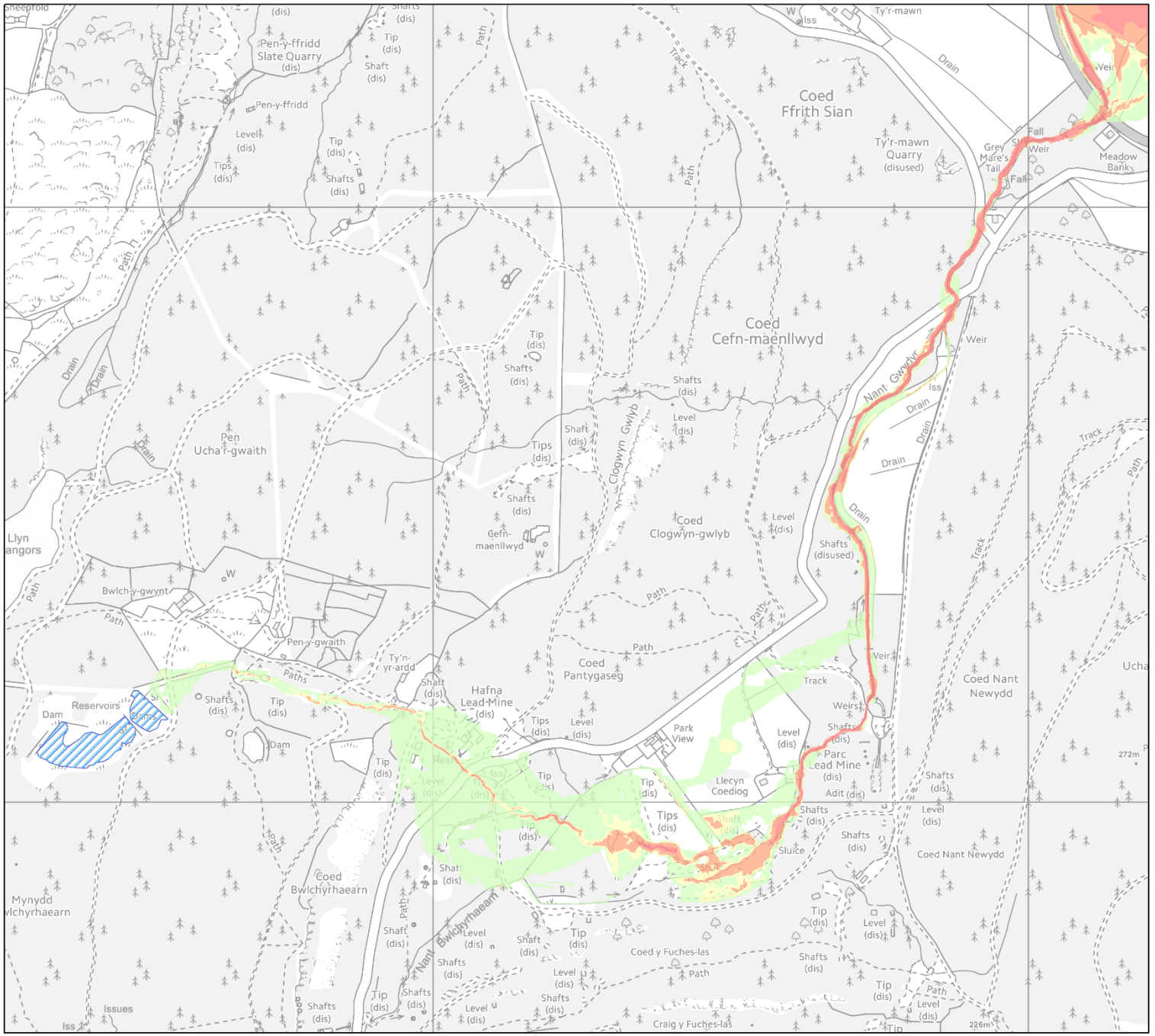
Maximum velocity
Baseline 1,000-year FSR/FEH event

Scale: 1:6,000	Drawn	CF
	Checked	CS
Original @ A3	Approved	CS

Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_014	Sheet No: 1 of 1	Status: Final	Rev: A

Drawing no. 015

Return to list of drawings



Reservoir extent marker

Hazard Rating:

- < 0.75 (Very low hazard)
- 0.75 - 1.25 (Danger for some)
- 1.25 - 2.0 (Danger for most)
- > 2.0 (Danger for all)

0 50 100 200 Metres

Information Warning:
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Hazard Rating
Baseline 1,000-year FSR/FEH event

Scale: 1:6,000	Drawn	CF
	Checked	CS
Original @ A3	Approved	CS

Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_015	Sheet No: 1 of 1	Status: Final	Rev: A

Drawing no. 016

Return to list of drawings

Reservoir extent marker

Change in flood extent from baseline:

Was Wet Now Dry

Was Dry Now Wet

Information Warning:
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Impact of Option 1A on flood extent 10-year event

Scale: 1:6,000	Drawn	CF
	Checked	CS
Original @ A3	Approved	CS

Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_016	Sheet No: 1 of 1	Status: Final	Rev: A

Drawing no. 017

Return to list of drawings

Reservoir extent marker

Depth difference (mm):

- > -100
- -5 to -100
- -5 to +5 (No change)
- +5 to +100
- > +100

0 50 100 200 Metres

Information Warning:
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Depth difference
Option 1A minus Baseline
10-year event

Scale: 1:6,000	Drawn	CF
	Checked	CS
Original @ A3	Approved	CS

Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_017	Sheet No: 1 of 1	Status: Final	Rev: A

Drawing no. 018

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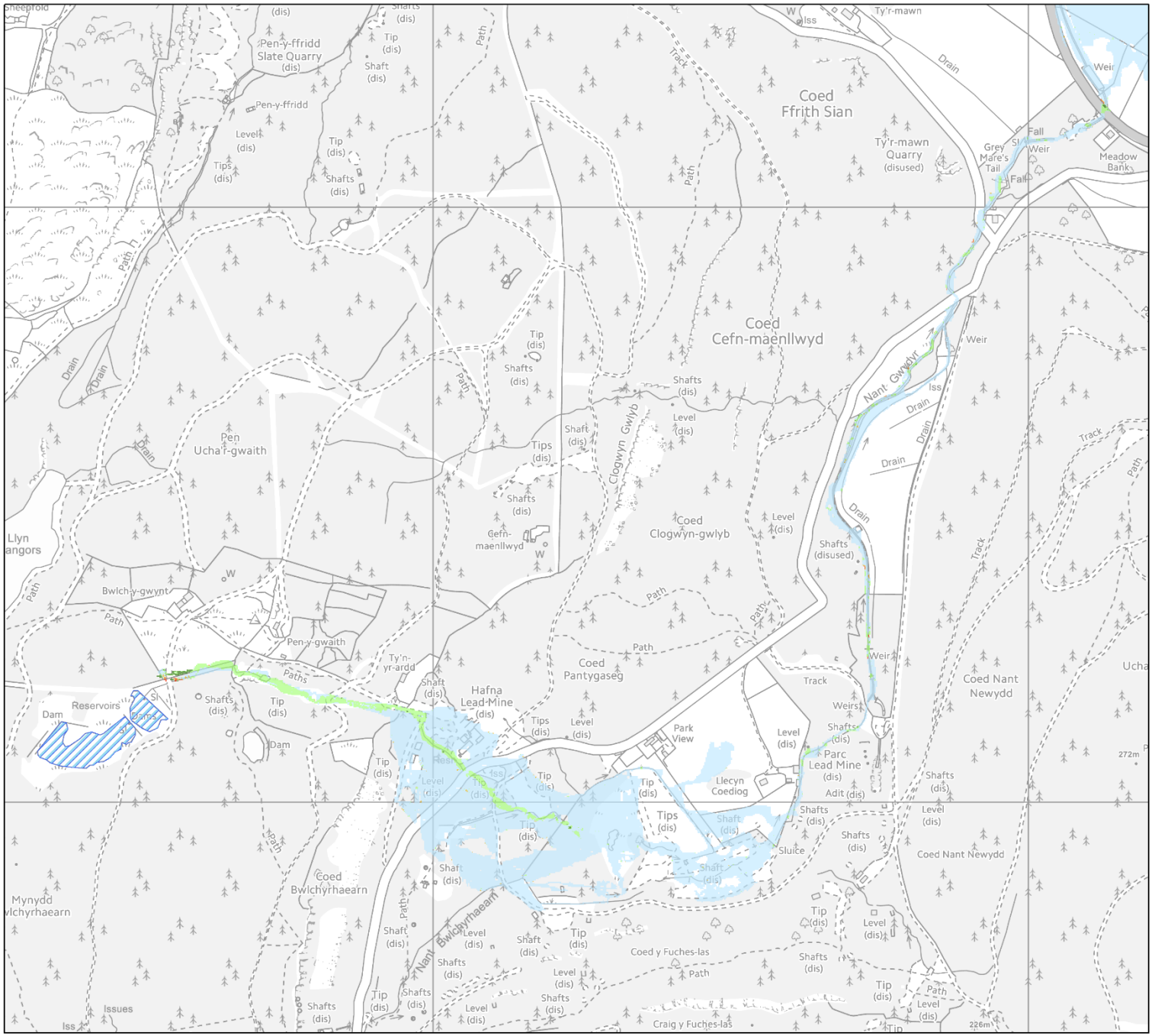

Reservoir extent marker

Velocity difference (m/s):

- > -0.1
- -0.02 to -0.1
- -0.02 to +0.02
- +0.02 to +0.1
- > +0.1

0 50 100 200 Metres

Information Warning:
This map gives an indication of the areas that may be flooded during a fluvial flood event, taking account of reservoir outflow. It is based on a simplified modelling approach and is intended for strategic flood risk assessment purposes only.

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Velocity difference
Option 1A minus Baseline
10-year event

Scale: 1:6,000	Drawn	CF
	Checked	CS
Original @ A3	Approved	CS

Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_018	Sheet No: 1 of 1	Status: Final	Rev: A

Drawing no. 019

Return to list of drawings

Reservoir extent marker

Change in flood extent from baseline:

Was Wet Now Dry

Was Dry Now Wet

0 50 100 200

Metres

Information Warning:
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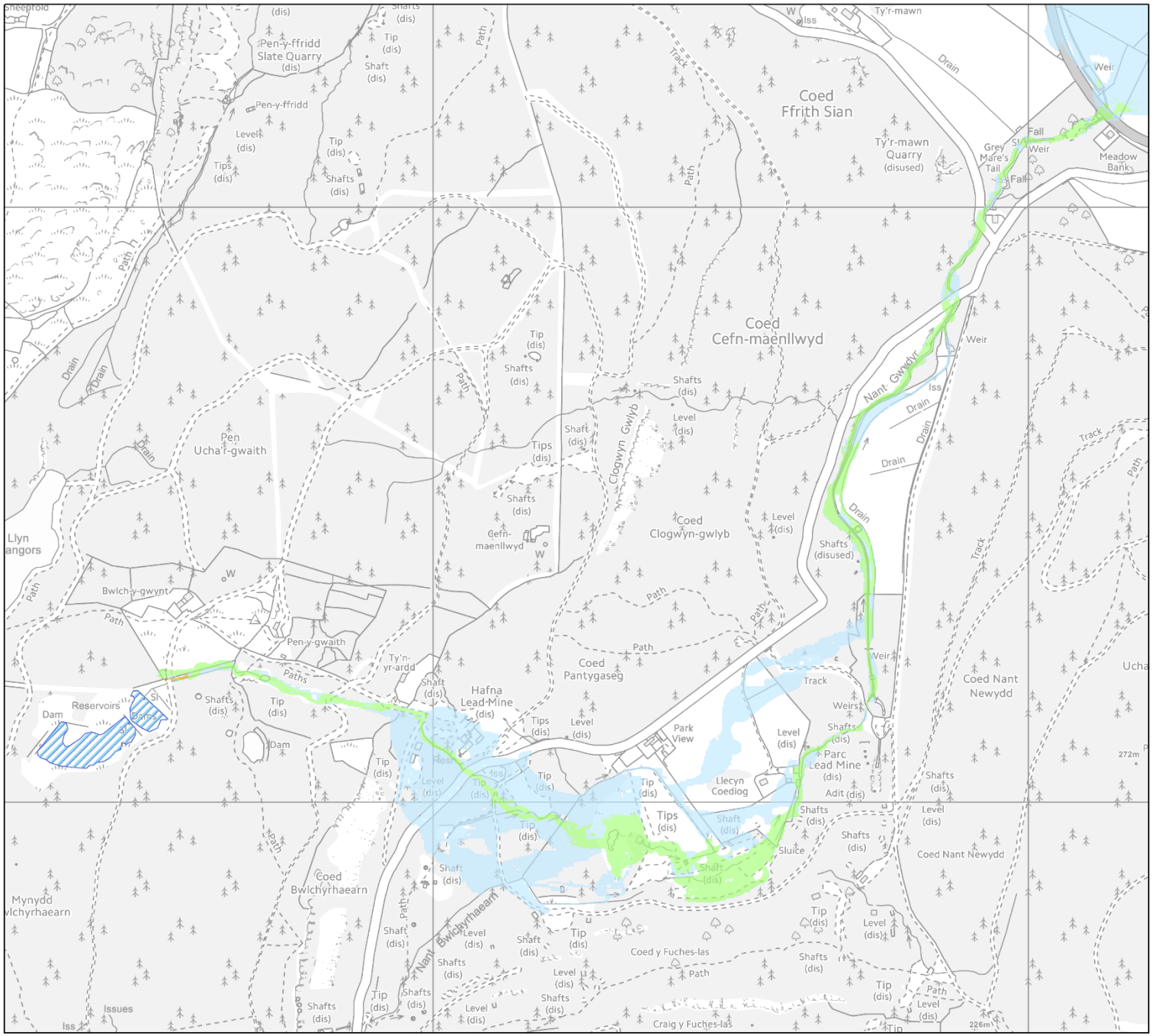
Impact of Option 1A on flood extent 1,000-year event

Scale: 1:6,000	Drawn	CF
	Checked	CS
Original @ A3	Approved	CS

Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_019	Sheet No: 1 of 1	Status: Final	Rev: A

Drawing no. 020

Return to list of drawings



Reservoir extent marker

Depth difference (mm):

- > -100
- -5 to -100
- -5 to +5 (No change)
- +5 to +100
- > +100

0 50 100 200 Metres

Information Warning:
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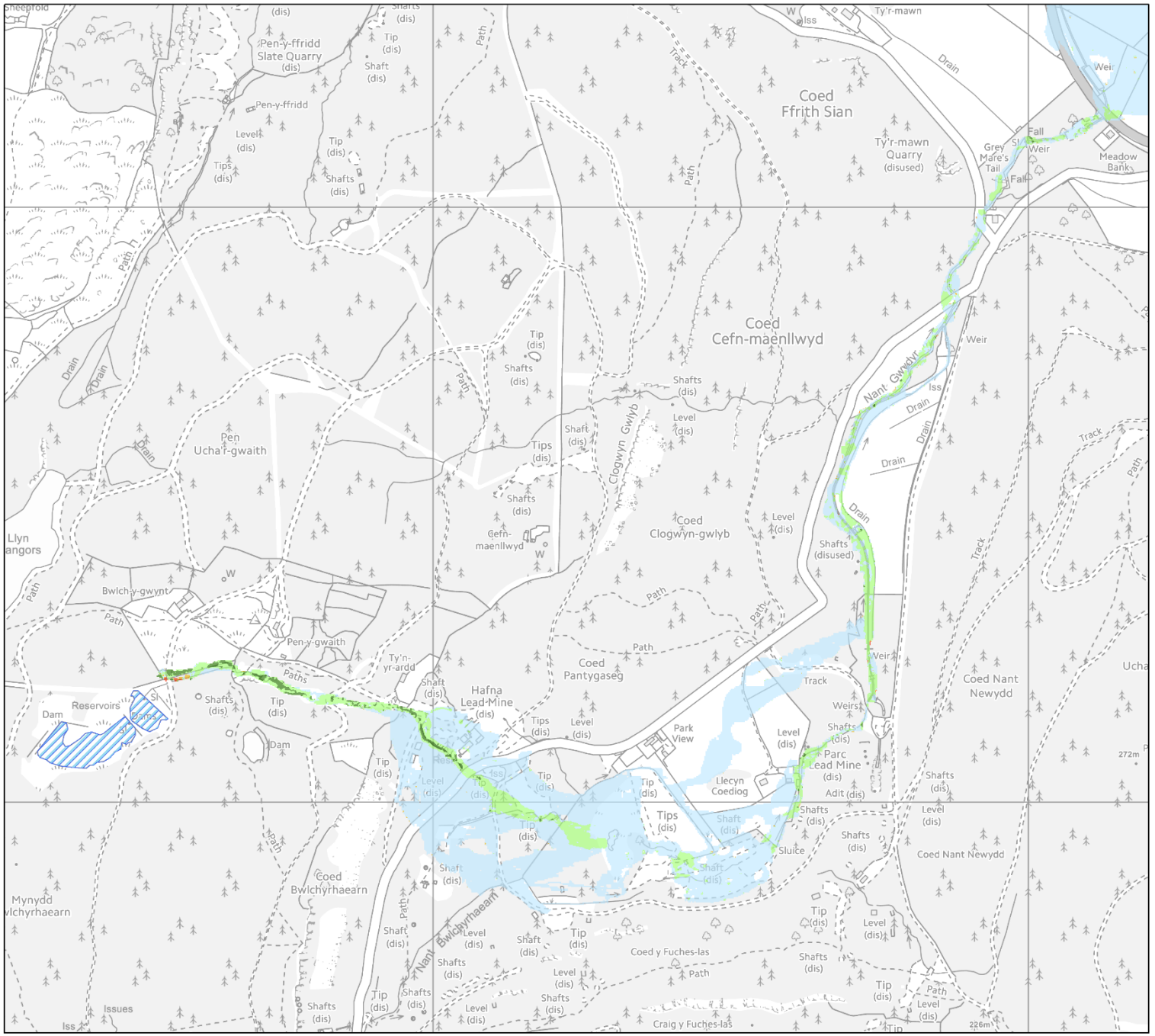
Depth difference
Option 1A minus Baseline
1,000-year event

Scale: 1:6,000	Drawn	CF
	Checked	CS
Original @ A3	Approved	CS

Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_020	Sheet No: 1 of 1	Status: Final	Rev: A

Drawing no. 021

Return to list of drawings



Reservoir extent marker

Velocity difference (m/s):

- > -0.1
- -0.02 to -0.1
- -0.02 to +0.02
- +0.02 to +0.1
- > +0.1

0 50 100 200 Metres

Information Warning:
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Velocity difference
Option 1A minus Baseline
1,000-year event

Scale: 1:6,000	Drawn	CF
	Checked	CS
Original @ A3	Approved	CS

Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_021	Sheet No: 1 of 1	Status: Final	Rev: A

Drawing no. 022

Return to list of drawings

Reservoir extent marker

Change in flood extent from baseline:

Was Wet Now Dry

Was Dry Now Wet

Information Warning:
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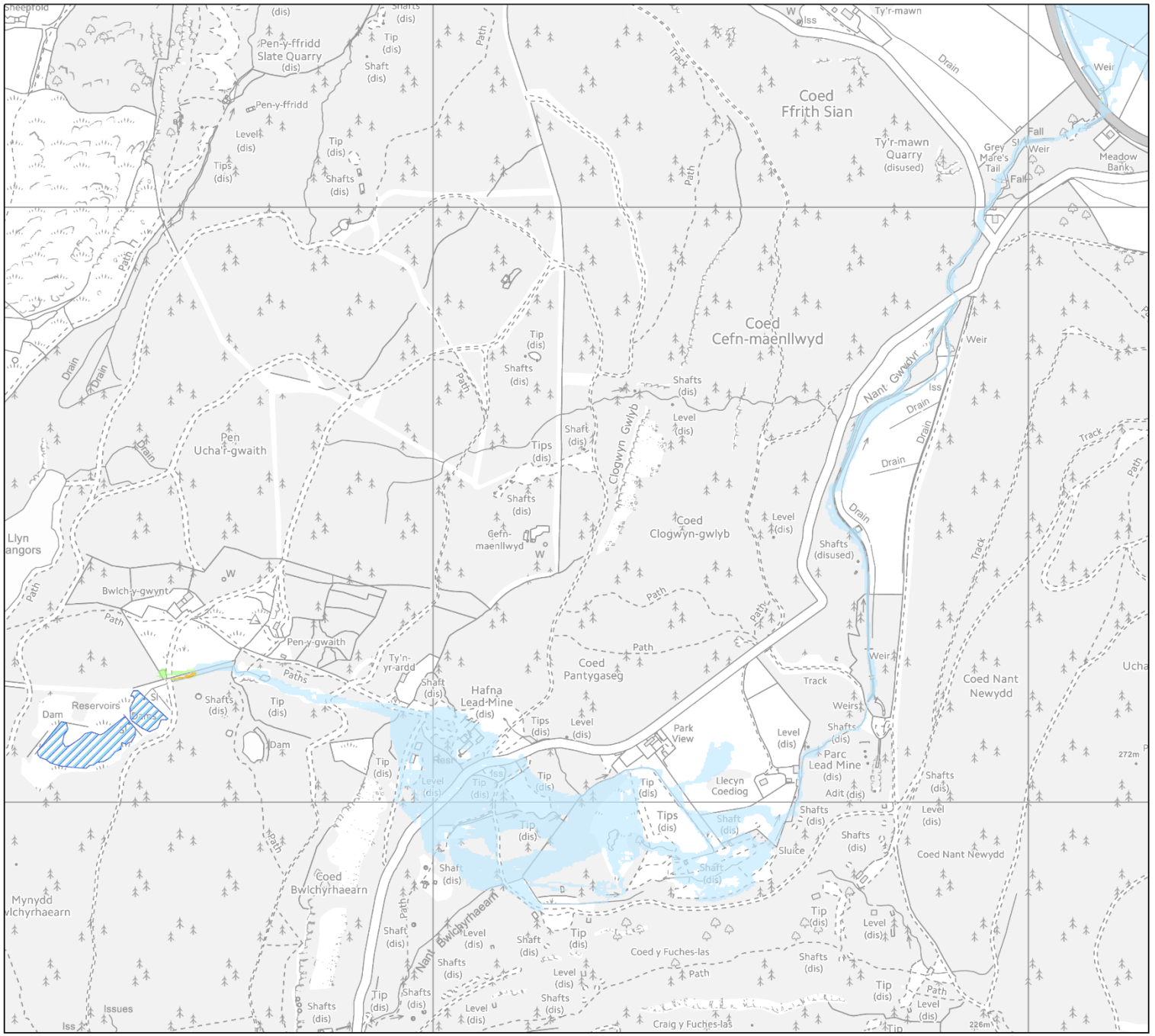
Impact of Option 1C on flood extent 10-year event

Scale: 1:6,000	Drawn	CF
	Checked	CS
Original @ A3	Approved	CS

Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_022	Sheet No: 1 of 1	Status: Final	Rev: A

Drawing no. 023

Return to list of drawings



Reservoir extent marker

Depth difference (mm):

- > -100
- -5 to -100
- -5 to +5 (No change)
- +5 to +100
- > +100

0 50 100 200 Metres

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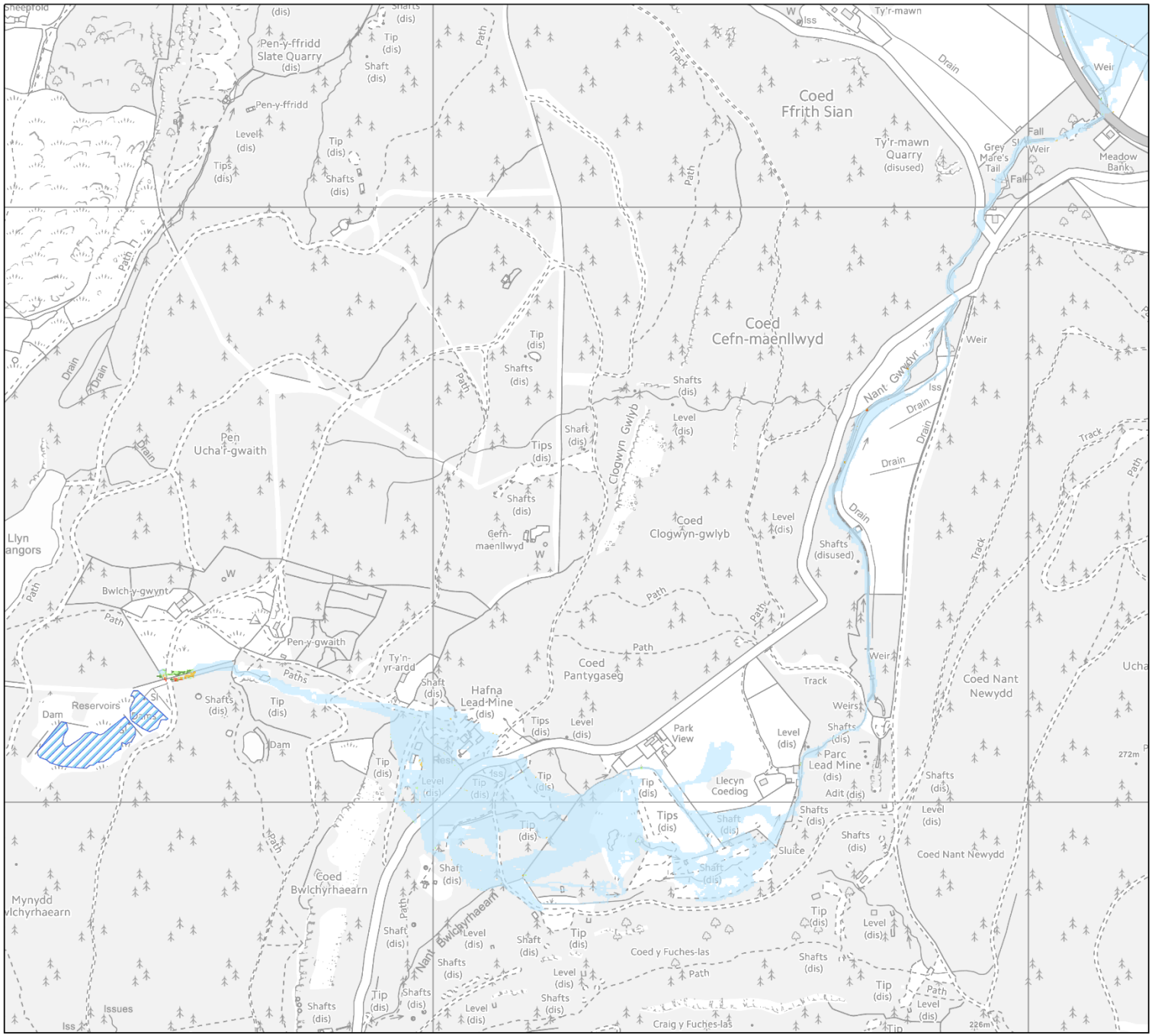
Depth difference
Option 1C minus Baseline
10-year event

Scale: 1:6,000	Drawn	CF
	Checked	CS
Original @ A3	Approved	CS

Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_023	Sheet No: 1 of 1	Status: Final	Rev: A

Drawing no. 024

Return to list of drawings



Reservoir extent marker

Velocity difference (m/s):

- > -0.1
- -0.02 to -0.1
- -0.02 to +0.02
- +0.02 to +0.1
- > +0.1

Information Warning:
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Velocity difference
Option 1C minus Baseline
10-year event

Scale: 1:6,000	Drawn	CF
	Checked	CS
Original @ A3	Approved	CS

Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_024	Sheet No: 1 of 1	Status: Final	Rev: A

Drawing no. 025

Return to list of drawings

Reservoir extent marker

Change in flood extent from baseline:

Was Wet Now Dry

Was Dry Now Wet

0 50 100 200

Metres

Information Warning:
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Impact of Option 1C on flood extent 1,000-year FSR/FEH event

Scale: 1:6,000	Drawn	CF
	Checked	CS
Original @ A3	Approved	CS

Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_025	Sheet No: 1 of 1	Status: Final	Rev: A

Drawing no. 026

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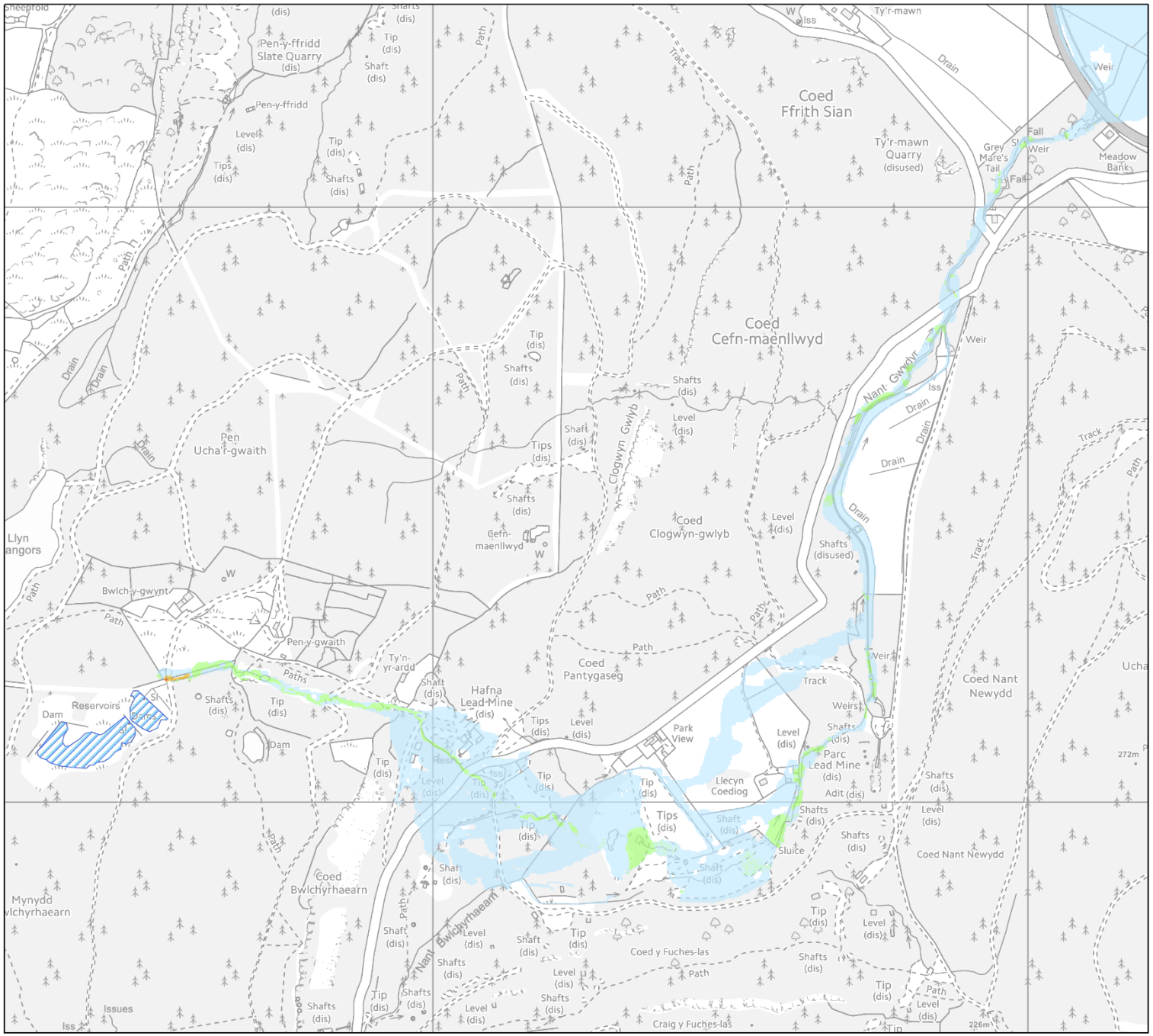

Reservoir extent marker

Depth difference (mm):

- > -100
- -5 to -100
- -5 to +5 (No change)
- +5 to +100
- > +100

0 50 100 200 Metres

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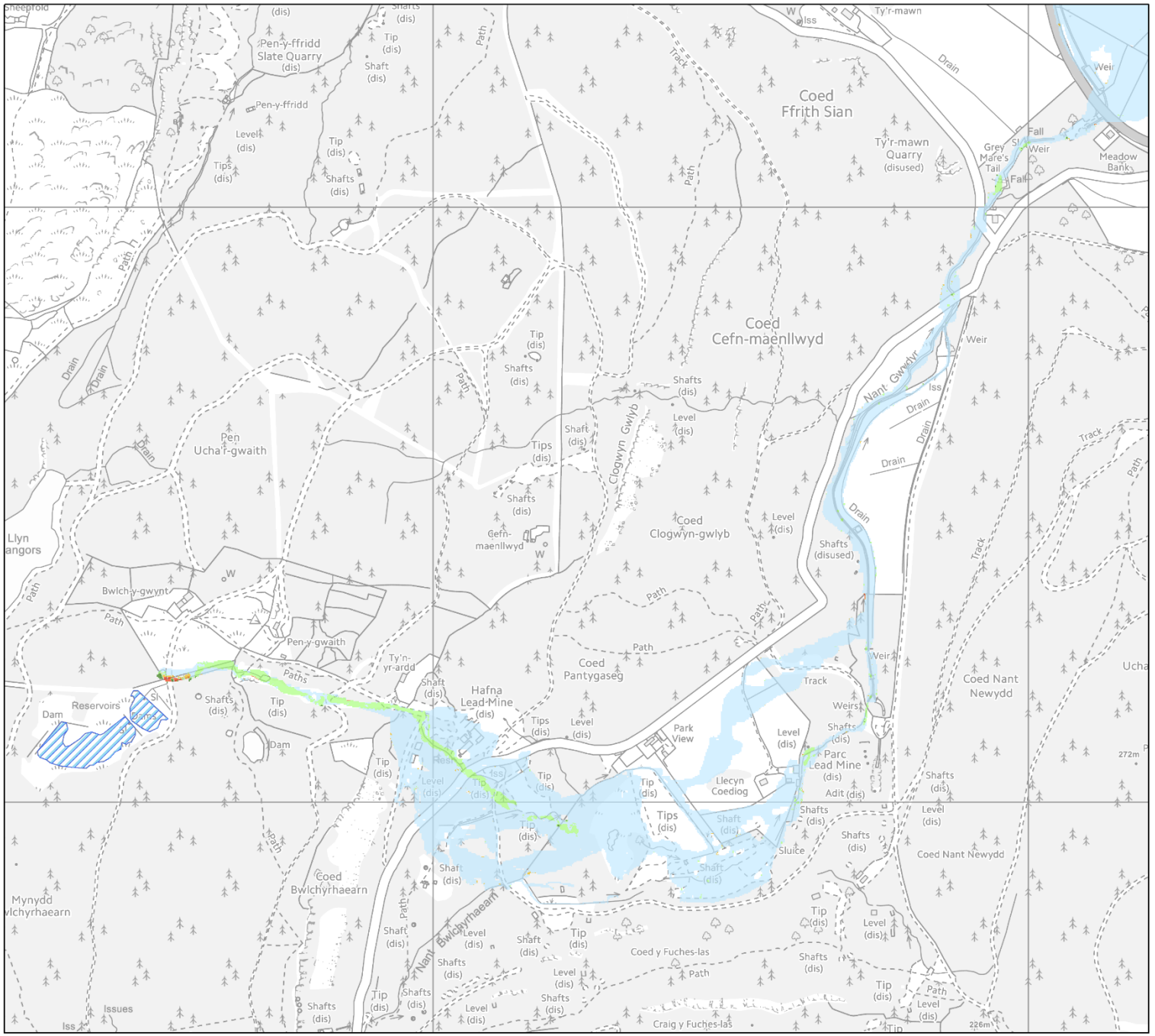
Depth difference
Option 1C minus Baseline
1,000-year FSR/FEH event

Scale: 1:6,000	Drawn	CF
	Checked	CS
Original @ A3	Approved	CS

Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_026	Sheet No: 1 of 1	Status: Final	Rev: A

Drawing no. 027

Return to list of drawings



Reservoir extent marker

Velocity difference (m/s):

- > -0.1
- -0.02 to -0.1
- -0.02 to +0.02
- +0.02 to +0.1
- > +0.1

0 50 100 200 Metres

Information Warning:
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Velocity difference
Option 1C minus Baseline
1,000-year FSR/FEH event

Scale: 1:6,000	Drawn	CF
	Checked	CS
Original @ A3	Approved	CS

Project Name:	Pen Y Gwaith (Upper & Lower) FCA		
Drawing Number: 2018s0401_027	Sheet No: 1 of 1	Status: Final	Rev: A

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