

Technical Note

Project: Coed Darcy

Subject: North Site Reservoir Hydraulic Modelling

Client:	St. Modwen Developments	Version:	R1
Project No:	04020	Author:	SM
Date:	07 November 2024	Approved:	CTM

I Introduction

- 1.1.1 PJA was commissioned by St. Modwen Developments to undertake a hydraulic modelling exercise to support a Flood Consequence Assessment (FCA) for the North Site Reservoir (NSR) at Coed Darcy, west of Neath, South Wales.
- 1.1.2 The hydraulic modelling exercise aims to understand the existing hydrological regime and a future scenario where the reservoir impoundment is removed, and a channel allowed to re-naturalise. The modelling supports the FCA by providing the evidence base to assess any implications for downstream flood risk resulting from the removal of the dam and to inform the design of the re-naturalised channel and any associated attenuation.

2 North Site Reservoir

- 2.1.1 The NSR is a large artificial waterbody constructed during the operation of the former Llandarcy Oil Refinery. It is understood to have primarily been used to store water for use in firefighting. Water levels within the NSR have been artificially managed for decades, both as part of the operational use of the former oil refinery and since the refinery was decommissioned. This management, which has remained ongoing, has been in the form of pumping and discharge of water from the NSR via the consented trade effluent, which outfalls to the River Neath to the east.
- 2.1.2 Discussions are ongoing between the Coombe Tennant Estate, as landowner, and St. Modwen Developments on the requirements of the condition of the land at 'hand back'. At this stage it is

anticipated that the NSR will be ‘restored’ to a grassed valley, inclusive of areas of open water and a watercourse.

- 2.1.3 The Site context at the NSR, including significant structures and impoundments, is shown in Figure 1.

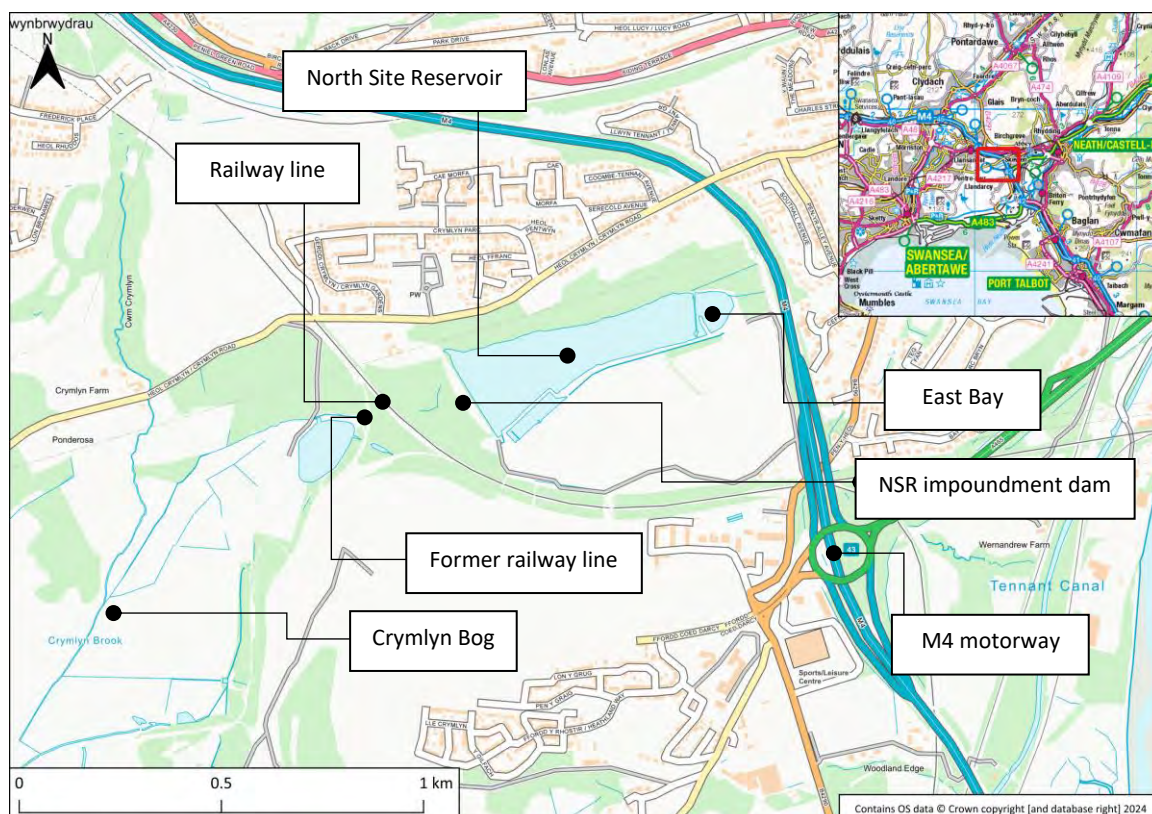


Figure 1: NSR site context

3 Hydraulic modelling

- 3.1.1 A hydraulic model was constructed using TUFLOW, the latest publicly available LIDAR DTM, and topographic survey of the NSR and adjacent watercourses between the M4 and Crymlyn Bog.
- 3.1.2 A summary of the TUFLOW hydraulic model is included in Table 1:

Table 1: Hydraulic model summary

Modelling element	Description
Summary of approach	1D-2D linked TUFLOW
Software	TUFLOW 2023-AD
Timesteps	0.5 second (1D) and 1 second (2D)
2D model resolution	2 m

Modelling element	Description
Available data	- LIDAR Digital Terrain Model, downloaded from DataMapWales February 2024 - Watercourse survey undertaken by Greenhatch Group in February 2024 (Appendix A) - Topographic survey of the NSR collected by Greenhatch Group in February 2024 (Appendix B)
Watercourses	All watercourses between the M4 and the Crymlyn Bog are represented as cross sections in the 1D model. Watercourse cross sections are informed by the watercourse survey undertaken by Greenhatch Group in February 2024 (Appendix A).
Structures	All structures between the M4 and the Crymlyn Bog are represented in the 1D model. All structures are informed by the watercourse survey undertaken by Greenhatch Group in February 2024 (Appendix A).
Hydraulic roughness	Manning's n roughness coefficients for the 1D model (variable across watercourse cross sections) and 2D model (as TUFLOW .tmf)

3.1.3 The TUFLOW hydraulic model schematic is shown in Figure 2.

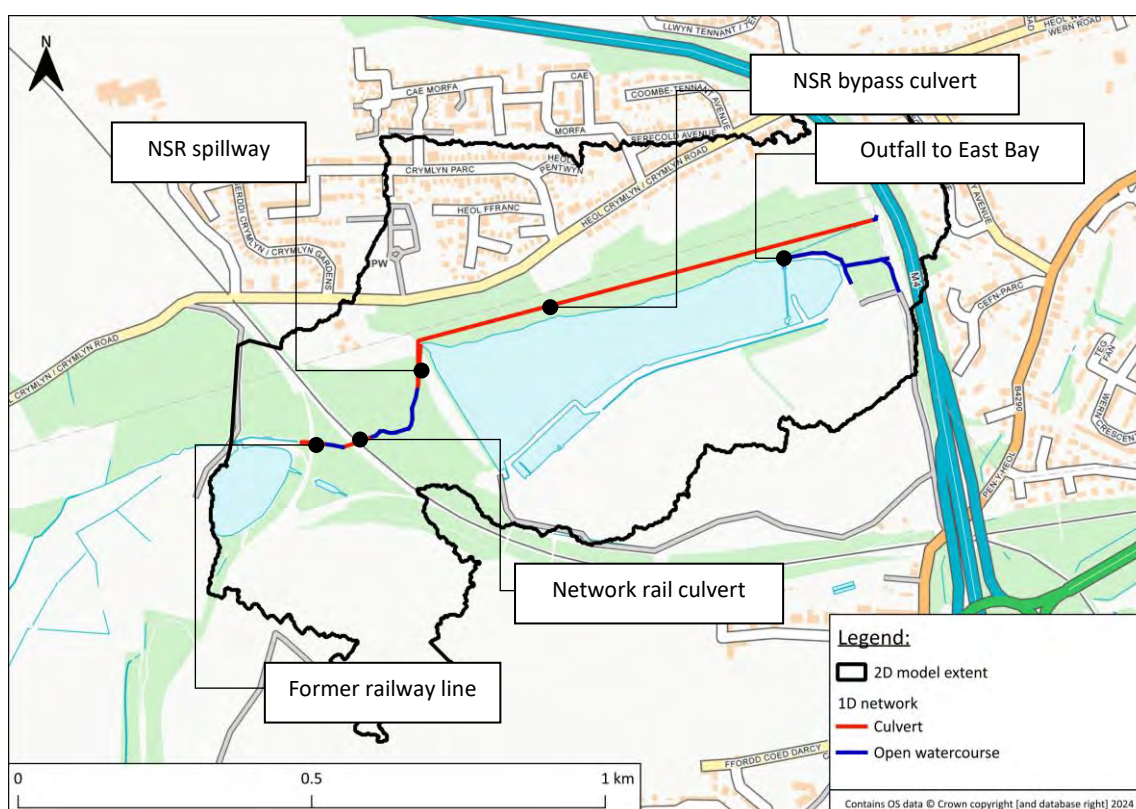


Figure 2: NSR hydraulic model schematic

4 Hydrology

4.1.1 A hydrological analysis and associated Flood Estimation Report for Coed Darcy and the NSR was delivered by Hydrogreen Consulting Ltd for PJA in July 2024.

- 4.1.2 The Flood Estimation Report is included in Appendix C.
- 4.1.3 A hydrological analysis was required to derive inflow hydrographs to be input to the TUFLOW hydrodynamic hydraulic model.
- 4.1.4 The ReFH2 method was selected for the derivation of peak flows since it is based on the physical characteristics of the catchment itself. The relatively low values of peak flow from the statistical method are probably primarily due to the very low value of FARL (Flood Attenuation due to Reservoirs and Lakes) for the FEH web service catchment due to the presence of the large reservoir. The ReFH2 method does not use FARL in calculating flows. The purpose of this study is to model the difference in flood risk with and without the reservoir in place using a hydraulic model, and therefore the ReFH2 method which does not use FARL is the more appropriate one to use for this catchment. The peak flows from the ReFH2 method are more than twice as large as those from the FEH statistical.
- 4.1.5 Inflow hydrographs were derived in the ReFH2.3 software for the Coed Darcy catchment. These were then area-weighted between the various catchments shown below to derive the final model inflow hydrographs.
- 4.1.6 The East North, East Central, East South and West catchment flows were applied to the hydraulic model at the inflow points shown below. The Central catchment inflow was applied as a source area polygon upstream of the NSR dam.

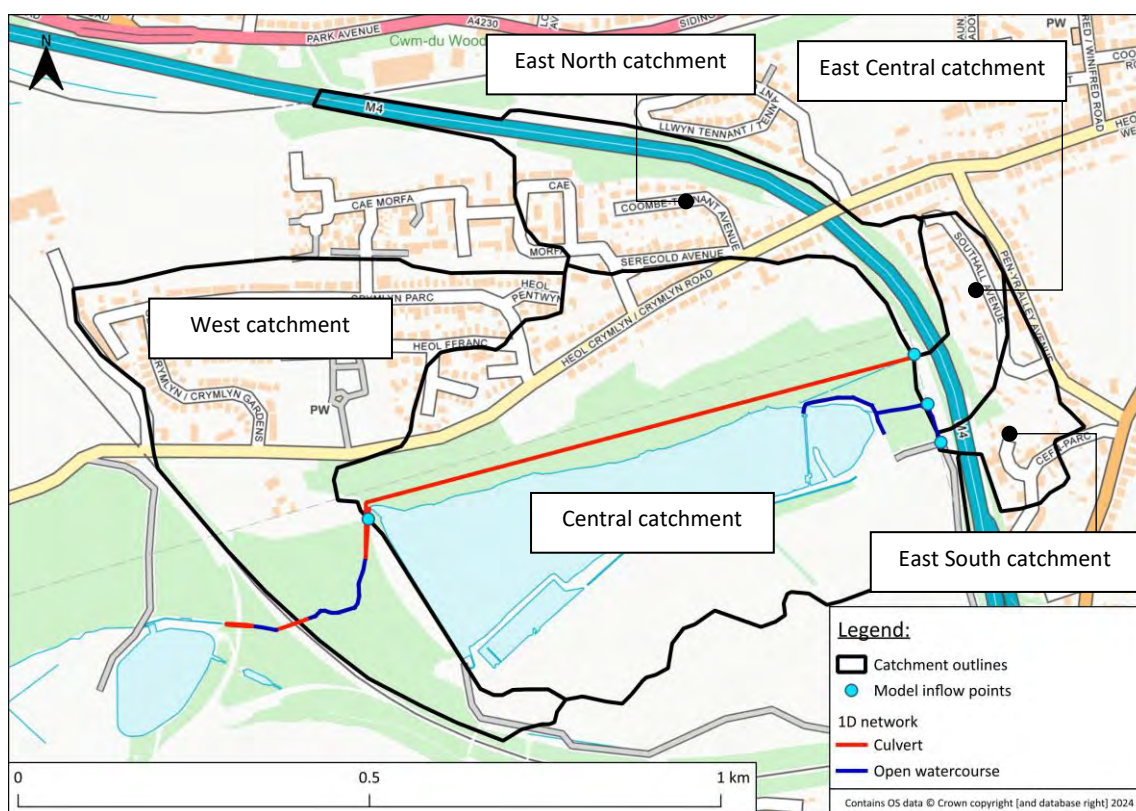


Figure 3: NSR catchments and inflow points

5 Hydraulic modelling baseline simulations

5.1.1 The model was simulated for a range of return periods, as follows:

- 2-year
- 30-year
- 100-year
- 100-year plus 40% climate change
- 1,000-year

6 Reservoir operating level

6.1.1 The impact of a heavy rainfall event in the NSR catchment on any infrastructure and the Crymlyn Bog downstream is highly sensitive to the antecedent or starting ('operating') water level in the NSR.

- 6.1.2 If the starting water level is below the level of the NSR spillway, there is sufficient storage within the reservoir to store the upstream inflows during a heavy rainfall event and the spillway remains inactive.
- 6.1.3 For the first baseline scenario, the starting water level in the reservoir was deemed to be a typical 'normal' operating water level of 29 mAOD. This is sufficiently below the spillway invert level for any upstream inflows to remain stored within the reservoir.
- 6.1.4 A separate simulation, or secondary baseline, was devised where the reservoir starts at full capacity, and any inflows into the reservoir from the upstream drainage channels, or falling directly to the reservoir itself, are conveyed to the NSR spillway. This represents a worst-case scenario for the infrastructure downstream and assumes that all ongoing maintenance of a 'normal' operating water level stops.
- 6.1.5 The results for each scenario are discussed below.

7 Baseline results

- 7.1.1 The modelling results are illustrated and discussed below.

7.2 Reservoir starting water level: 29 mAOD

- 7.2.1 The baseline maximum flood depth results for the 100-year plus climate change with a reservoir starting water level of 29 mAOD are shown in Figure 4.
- 7.2.2 The model illustrates the extent of water stored within the NSR and East Bay. Flood water enters East Bay either through the various drainage channels upstream, or as a result of exceedance of the capacity of the NSR bypass culvert and the excess water spilling over bank.
- 7.2.3 It is important to reiterate that any flow passing downstream of the NSR for this scenario is a result of the NSR bypass culvert. Due to the starting water level the NSR spillway is not active.
- 7.2.4 Downstream of the dam there is out of bank flooding from the watercourse as a result of water backing up behind the two culvert crossings.
- 7.2.5 Upstream of the railway line (cross section reference CoedDarcy01_12) the water level is 21.63 mAOD, which equates to a depth above the channel invert (19.84) of 1.79 m.

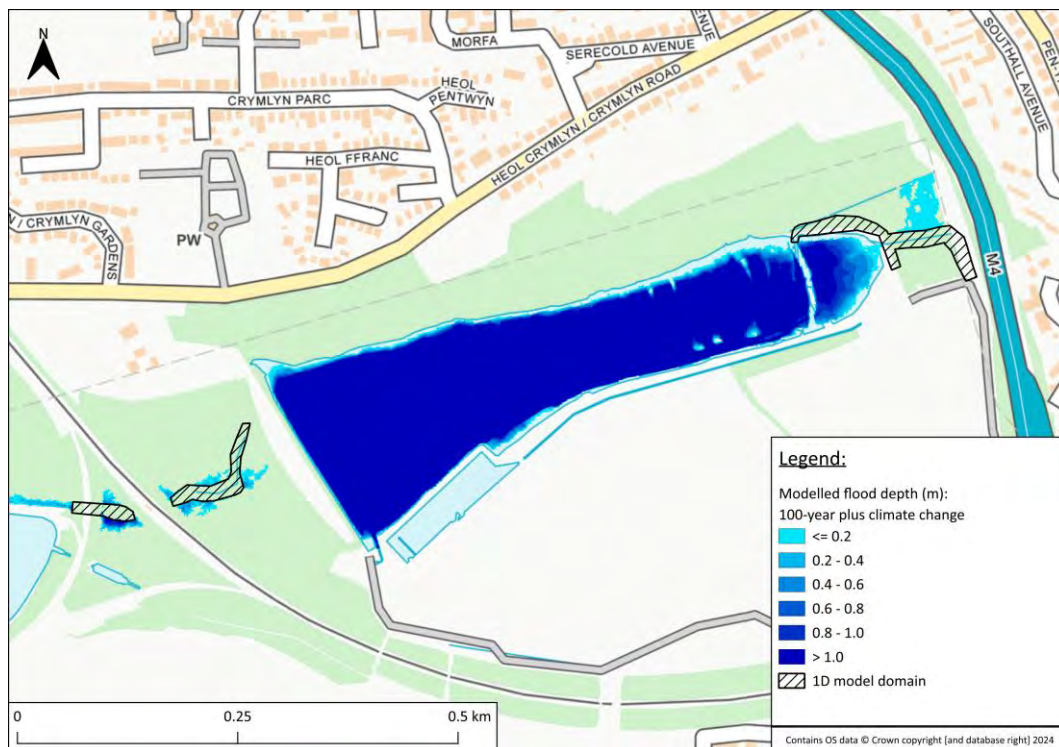


Figure 4: Reservoir starting water level 29 mAOD, 100-year plus climate change

7.3 Reservoir starting water level at full capacity

- 7.3.1 The baseline maximum flood depth results for the 100-year plus climate change with a reservoir starting water level at full capacity are shown in Figure 5.
- 7.3.2 This scenario assumes any inflows into the reservoir from the upstream drainage channels, or falling directly to the reservoir itself, are conveyed to the NSR spillway. This is assessed as the worst-case scenario prior to any proposed works.
- 7.3.3 This results in comparatively greater flood depths downstream of the NSR dam and upstream of the railway culvert.
- 7.3.4 Upstream of the railway line (cross section reference CoedDarcy01_12) the water level is 21.84 mAOD, which equates to a depth above the channel invert (19.84) of 2.00 m.

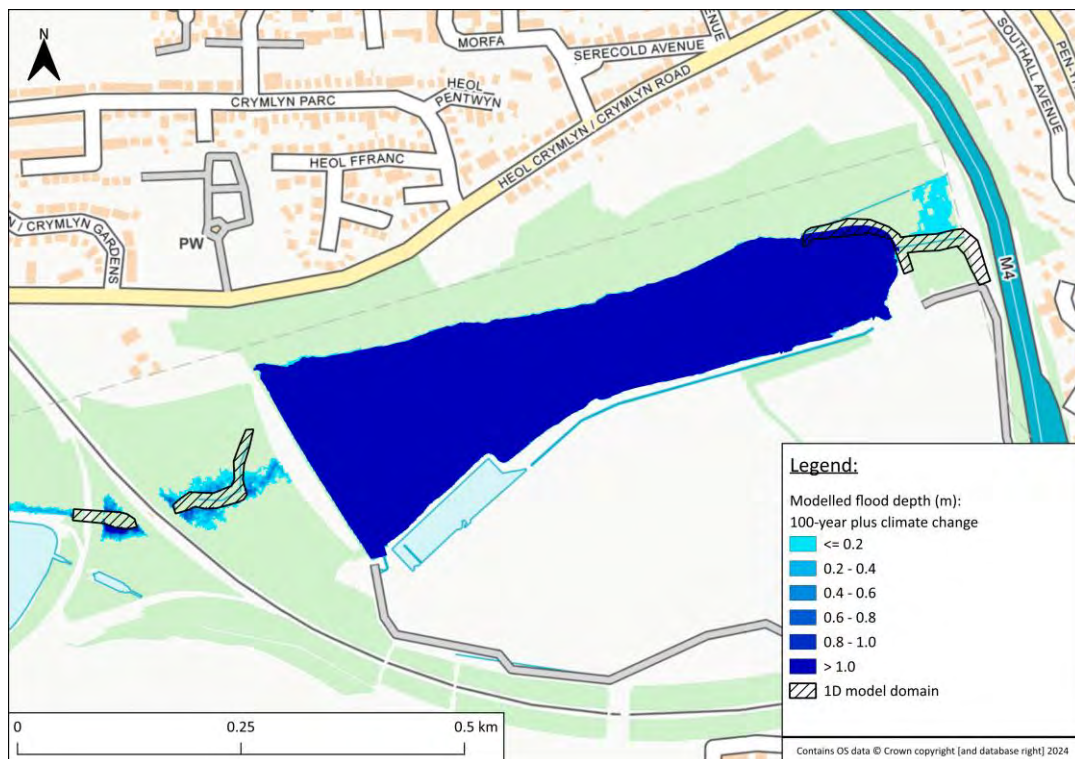


Figure 5: Reservoir at capacity results, 100-year plus climate change

8 Option testing

An iterative approach to the option testing was adopted to assess the relative impact of different potential interventions in isolation. This was carried out with the aim of providing an engineering solution that would not result in significantly severe flooding downstream of the dam following discontinuance. A final proposed post-discontinuance option, combining several different measures, was determined. These measures included:

- NSR fully drained;
- Removal of the NSR dam;
- Removal of the downstream former railway culvert to improve conveyance;
- Increased vegetation as a result of re-naturalisation within the former NSR (increased Manning's n roughness);
- Retention of the East Bay embankment, to provide some degree of attenuation at the eastern end of the valley; and,
- Incorporation of a 300 mm circular pipe through East Bay embankment to maintain a nominal flow through the former NSR under normal conditions.

9 Option results

9.1.1 The baseline maximum flood depth results for the 100-year plus climate change with the final proposed post-discontinuance option are shown in Figure 6.

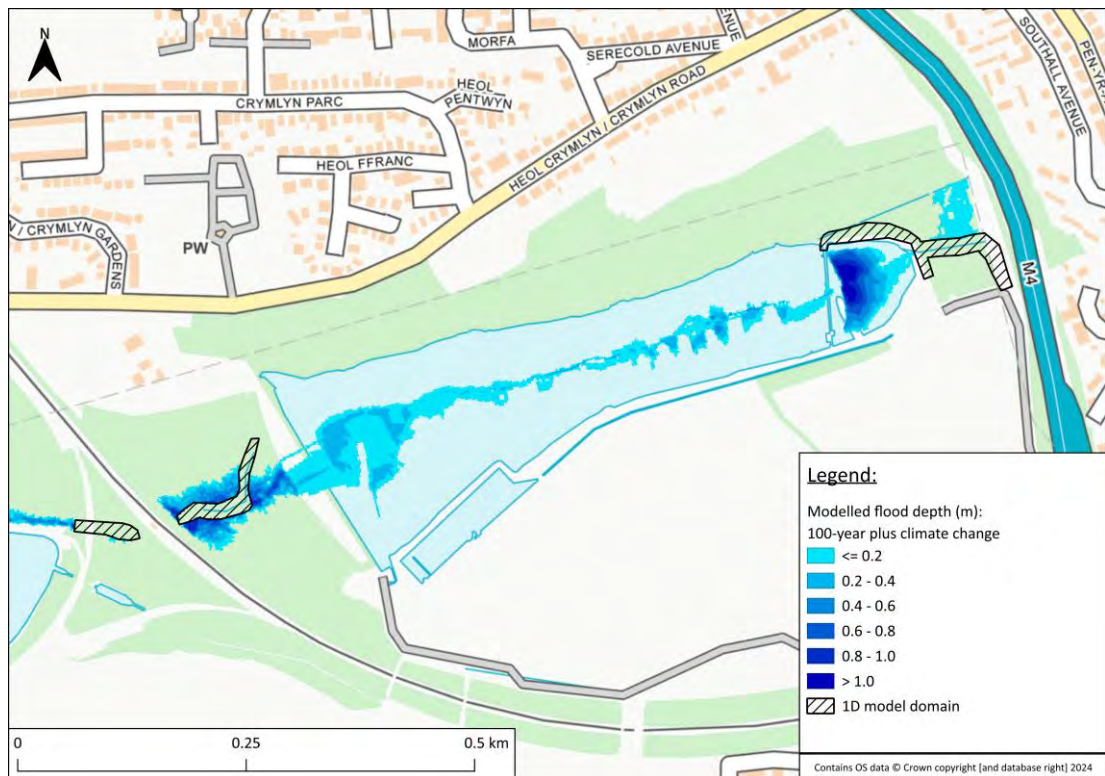


Figure 6: Post-discontinuance option results, 100-year plus climate change

9.1.2 The option results indicate the combined impact of several interventions associated with the post-discontinuance option. Removal of the NSR dam causes water to be displaced and stored upstream of the next flow constriction, which is the railway culvert. It is proposed that the downstream culvert, under the former railway line be removed to reduce the volume of water being stored upstream of the railway and improve conveyance. Retaining East Bay and capturing the re-naturalisation of the NSR through increased roughness aims to store water upstream to alleviate the volume of water upstream of the railway.

9.1.3 Upstream of the railway line (cross section reference CoedDarcy01_12) the water level is 22.13 mAOD, which equates to a depth above the channel invert (19.84) of 2.29 m.

9.1.4 Although the modelling indicates that there is an increase in water volume stored upstream of the railway culvert for the 100-year plus climate change flood event, primarily resulting from the removal of the dam, the impact is mitigated by storage upstream and improved conveyance

downstream. The engineered proposals tested with the modelling (listed in section 8) have been modelled to reduce flooding against the railway embankment to acceptable levels not dissimilar to those that would have been possible in the worst-case scenario prior to dam discontinuance.

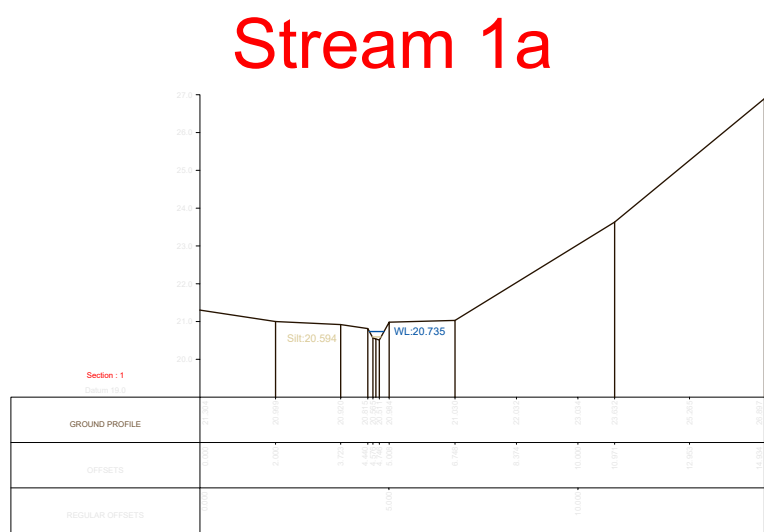
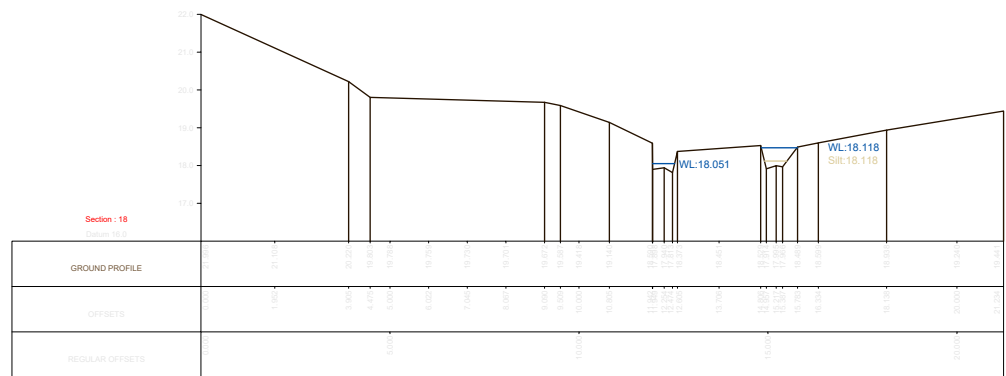
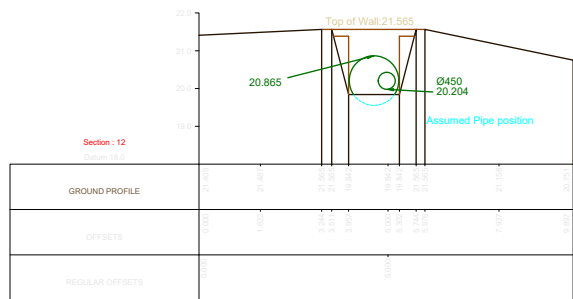
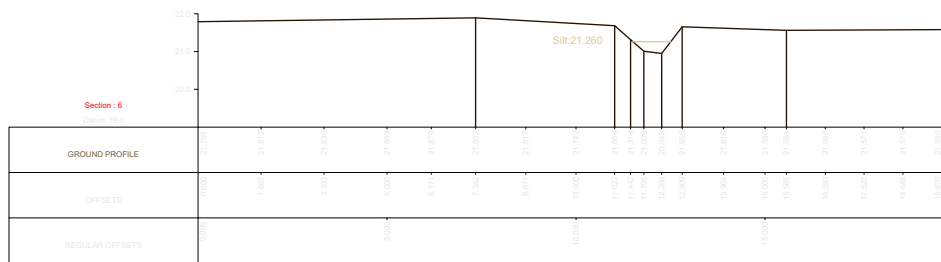
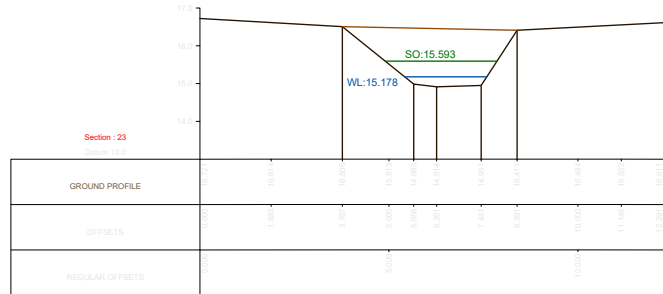
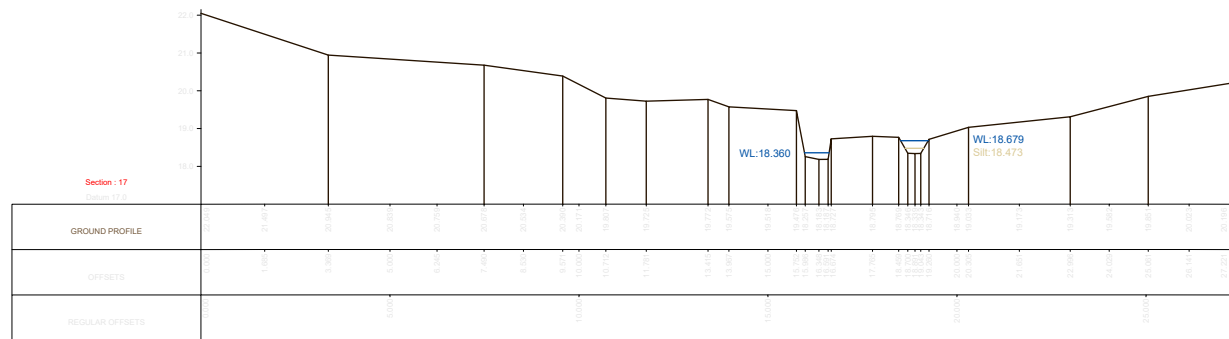
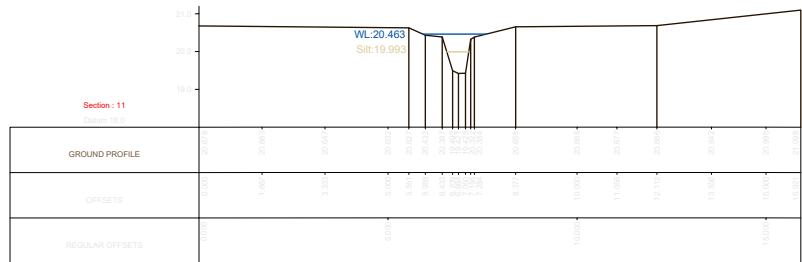
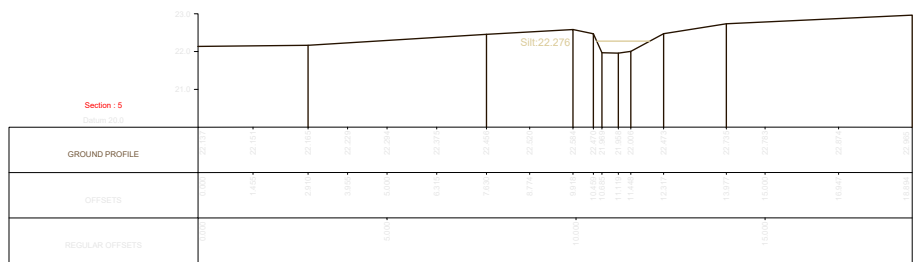
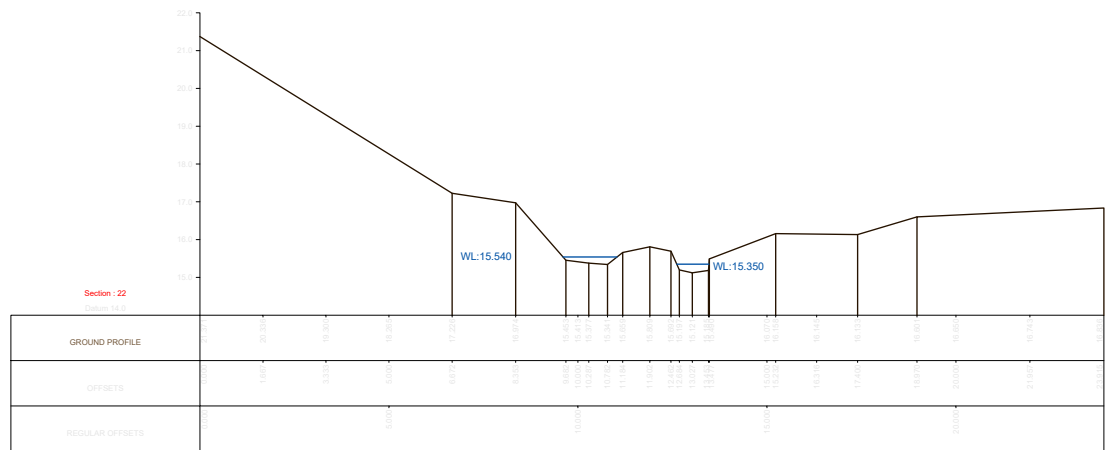
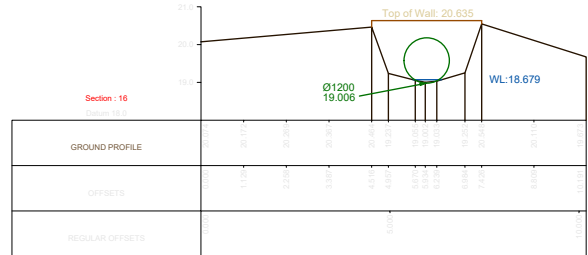
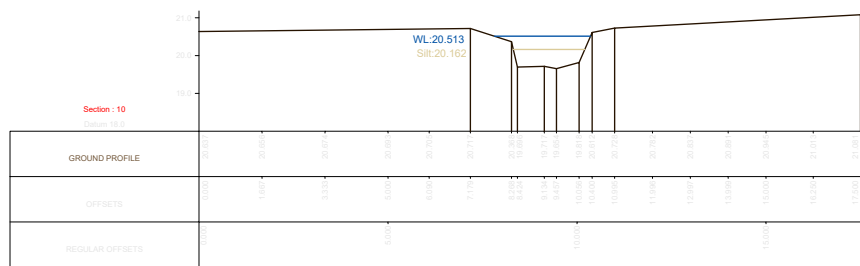
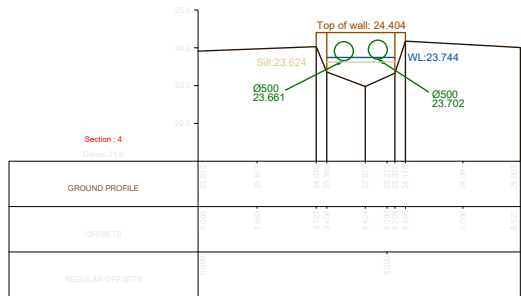
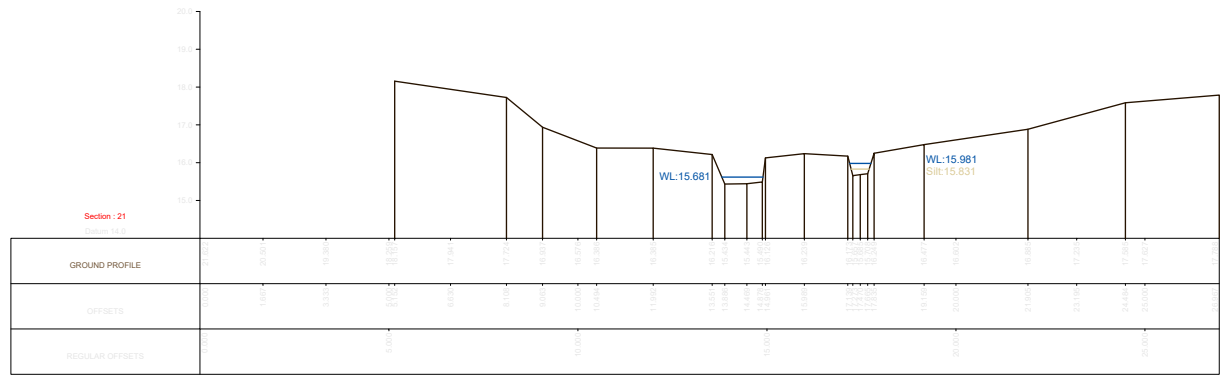
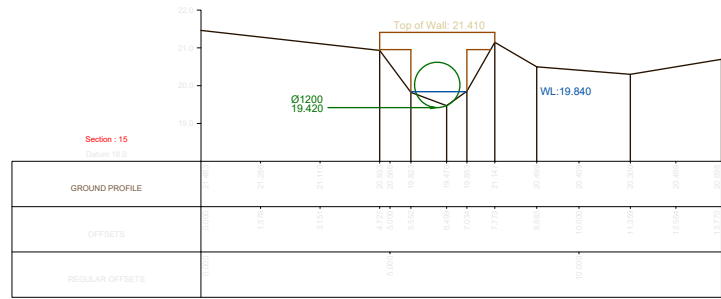
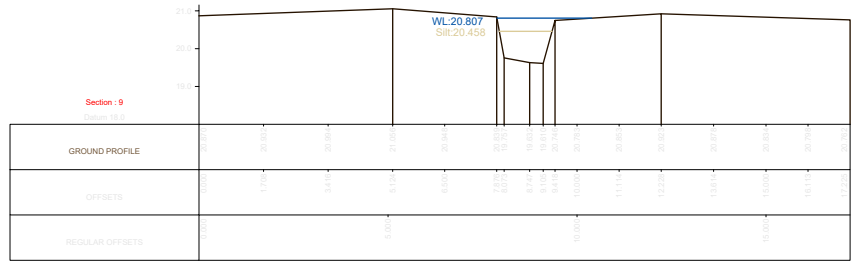
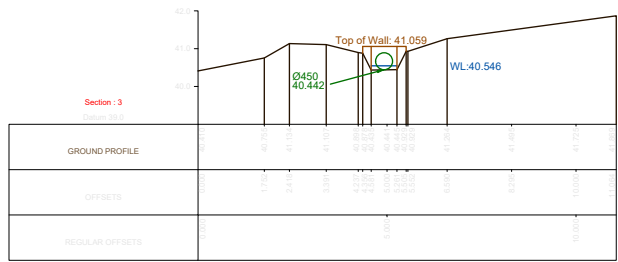
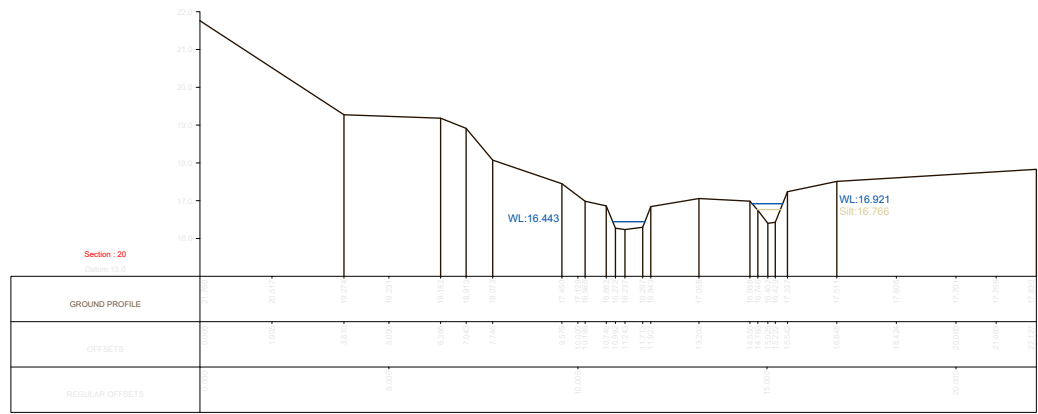
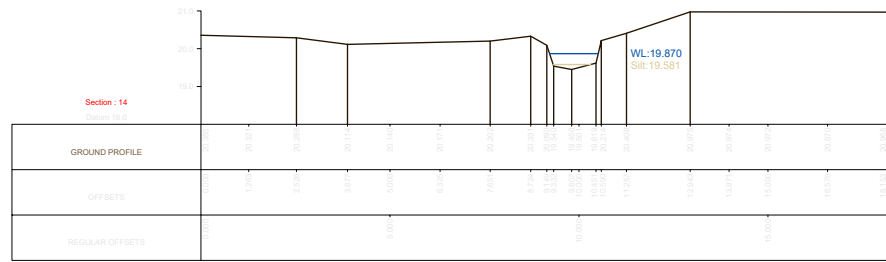
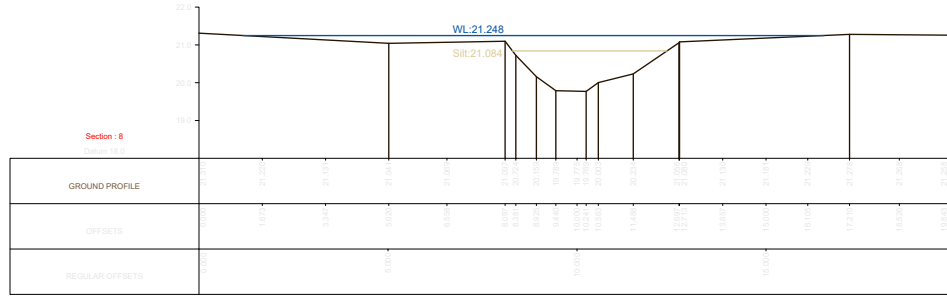
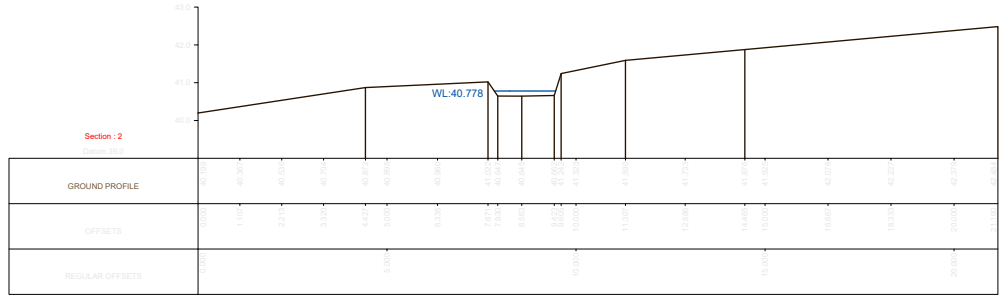
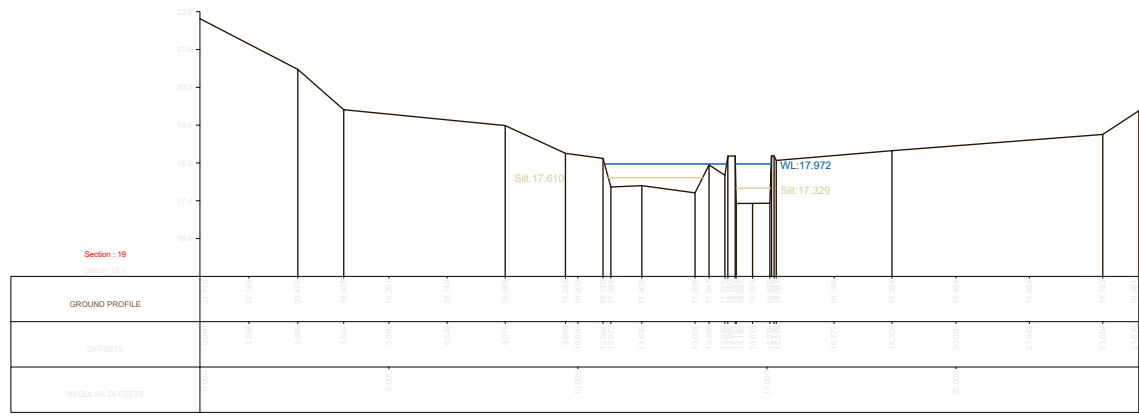
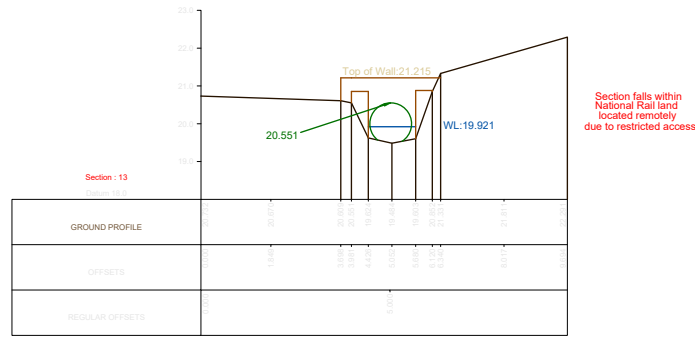
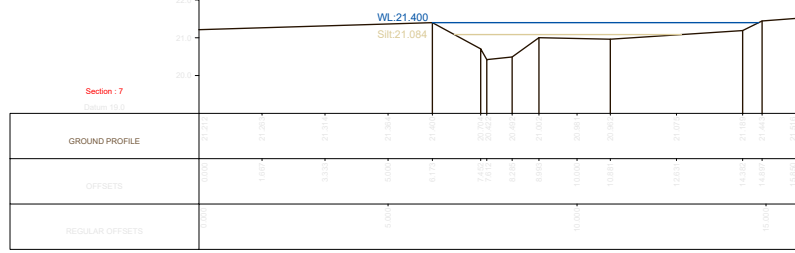
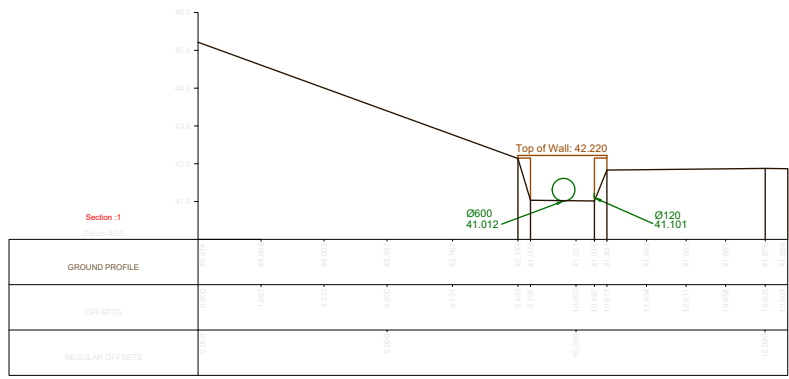
- 9.1.5 There has been no need to widen the channel or create additional sinuosity upstream of the dam. An engineered solution upstream demonstrated little additional benefit as part of the model option testing and the natural flow of the channel is acceptable.

10 Summary

- 10.1.1 The hydraulic modelling aims to understand the existing hydrological regime and a potential scenario where the NSR impoundment is removed, and the channel allowed to re-naturalise. The modelling supports the FCA by providing the evidence base to assess any implications for downstream flood risk resulting from the removal of the dam.
- 10.1.2 The impact of a heavy rainfall event in the NSR catchment on any infrastructure and the Crymlyn Bog downstream is highly sensitive to the starting ('operating') water level in the NSR.
- 10.1.3 Although the option modelling indicates that there is an increase in water volume stored upstream of the railway culvert for the 100-year plus climate change flood event, primarily resulting from the removal of the dam, the impact is mitigated by storage upstream and improved conveyance downstream.
- 10.1.4 Upstream of the railway line (cross section reference CoedDarcy01_12) the water level for the worst case, i.e. if the spillway is used, is 21.84 mAOD, which equates to a depth above the channel invert (19.84) of 2.00 m. Under the devised engineered mitigation scenario, the depth in this location increases by 290 mm.
- 10.1.5 The engineered mitigation scenario includes:
- NSR fully drained;
 - Removal of the NSR dam;
 - Removal of the downstream former railway culvert to improve conveyance;
 - Increased vegetation as a result of re-naturalisation within the former NSR (increased Manning's n roughness);
 - Retention of the East Bay embankment, to provide some degree of attenuation at the eastern end of the valley; and,
 - Incorporation of a 300 mm circular pipe through East Bay embankment to maintain a nominal flow through the former NSR under normal conditions.

Appendix A Watercourse survey, Greenhatch Group 2024

Stream 1



Stream 1a

Rev	Date	Description	Drawn	Q. Ref.
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- Topographical Surveys
- Site Engineering
- Utility / CCTV Surveys
- Measured Building Surveys
- 3D Laser Scanning
- Revit & BIM Models

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CLIENT St Modwen Developments	
PROJECT Coed Darcy Neath Port Talbot SA10 6EQ	
TITLE Cross section Survey	
SCALE A1@ 1: 200	DATE SURVEYED 26.02.2024
DRAWN SA	QUALITY REF GH20019
Level datum Grid orientation	N/A N/A
Job number	49771
Drawing No. 49771_T	Rev. 0
Comments This plan should only be used for its original purpose. Greenhatch Group accepts no responsibility for this plan if supplied to any party other than the original client. All dimensions should be checked on site prior to design and construction. Drainage information (where applicable) has been visually inspected from the surface and therefore should be treated as approximate only.	
Notes:	
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Stream 3

Section 1

Elevation (m)

Distance (km)

WL 34.471

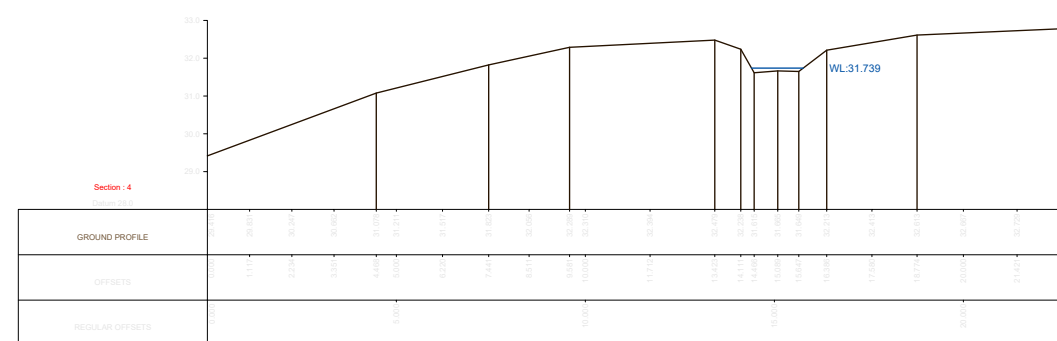
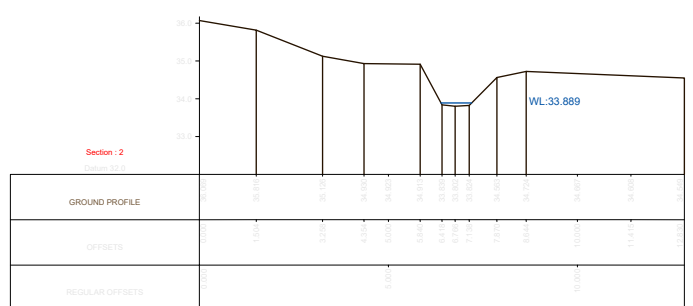
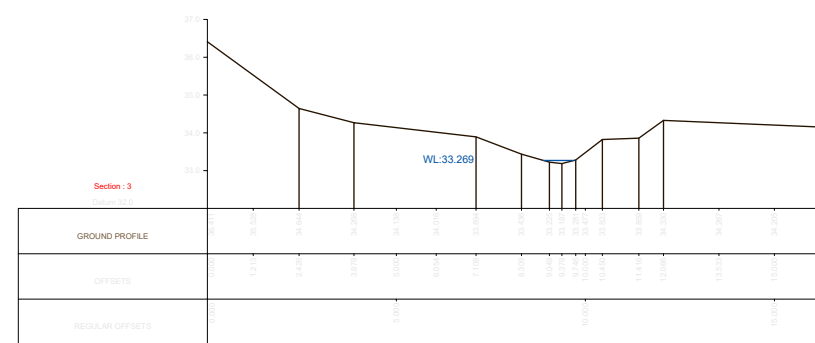
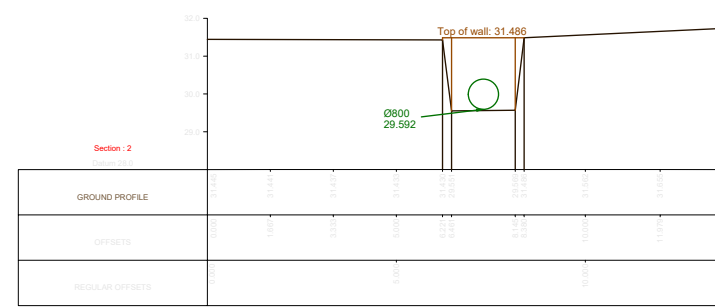


Figure 10 shows a cross-section of the ground profile. The top of the wall is at an elevation of 31.580. A green circle indicates a Ø450 x 432 pipe. The ground profile is shown as a solid line, and the proposed water level is shown as a dashed line. The section is labeled 'Section 1' and 'Ground Profile'.



Rev	Date	Description	Drawn	Q. Ref.

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- Topographical Surveys
- Site Engineering
- Utility / CCTV Surveys
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CLIENT
St Modwen Developments

PROJECT

**Coed Darcy
Neath Port Talbot
SA10 6EQ**

TITLE	Abstract
Cross section Survey	

SCALE	DATE SURVEYED
A1@ 1: 200	26.02.2024

DRAWN SA	QUALITY REF GH20019
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Level datum	N/A
Grid coordinates	N/A

Grid orientation	N/A
Job number	49771

Drawing No.	Rev.
49771_T	0

Comments

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Drainage information (where applicable) has been visually inspected from the surface and therefore should be treated as approximate only.

Appendix B Topographic survey of the NSR, Greenhatch Group 2024

Station	Easting (m)	Northing (m)	Level (m)
SA1	272002.135	196485.190	47.855
SA2	271994.221	196542.877	47.808
SA3	271998.455	196595.725	44.269
CC1	271840.974	196603.520	33.189
CC2	271786.810	196588.168	33.180

No scale factor has been applied to the survey therefore the coordinates shown are arbitrary & not true O.S. Coordinates which have a scale factor applied.

[illegible]

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- Topographical Surveys
- Site Engineering
- Utility / CCTV Surveys
- Measured Building Surveys
- 3D Laser Scanning
- Revit & BIM Models

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t. (01727) 854481	t. (01912) 736391	t. (02072) 241806

TITLE	Topographical Survey
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Level datum	See notes
Grid orientation	See notes

Drawing No.	Rev
49771 T	0

Comments

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All dimensions should be checked on site prior to design and construction.

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Appendix C Coed Darcy FEH Calculation Record

Flood estimation report:

Coed Darcy

Flood Consequence Assessment

Contents

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Approval

This document has been issued and amended as follows:

Version	Date	Description	Created by	Verified and Approved by
1.0	04/07/2024	Issued to client	M Green BEng, MSc, CEng, MCIWEM, C.WEM	M Green BEng, MSc, CEng, MCIWEM, C.WEM

Abbreviations

AEP	annual exceedance probability
AM	Annual Maximum
AREA	Catchment area (km ²)
BFI	Base Flow Index
BFIHOST	Base Flow Index derived using the HOST soil classification
CPRE	Council for the Protection of Rural England
FARL.....	FEH index of flood attenuation due to reservoirs and lakes
FEH	Flood Estimation Handbook
FSR	Flood Studies Report
HOST	Hydrology of Soil Types
NRFA	National River Flow Archive
OS.....	Ordnance Survey
POT.....	Peaks Over a Threshold
QMED.....	Median Annual Flood (with return period 2 years)
ReFH	Revitalised Flood Hydrograph method
ReFH2	Revitalised Flood Hydrograph 2 method
SAAR.....	Standard Average Annual Rainfall (mm)
SPR	Standard percentage runoff
SPRHOST.....	Standard percentage runoff derived using the HOST soil classification
Tp(0)	Time to peak of the instantaneous unit hydrograph
URBAN	Flood Studies Report index of fractional urban extent
URBEXT1990	FEH index of fractional urban extent
URBEXT2000	Revised index of urban extent, measured differently from URBEXT1990
WINFAP-FEH	Windows Frequency Analysis Package - used for FEH statistical method

1 SUMMARY OF ASSESSMENT

1.1 Summary

Catchment location	Coed Darcy, west of Neath, south Wales
Purpose of study and scope	A hydrological analysis to derive inflow hydrographs to be input to a hydrodynamic hydraulic 1D-2D model to check flood risk for a Flood Consequence Assessment at Coed Darcy, west of Neath in south Wales. The purpose of the modelling is to check the difference in flood risk with and without the reservoir in place.
Key catchment features	The site is at the top of a small and relatively steep and impermeable catchment draining south west into small watercourses which in turn drain into Swansea Bay south of the site.
Flooding mechanisms	The scope of this hydrological analysis is to provide inflow hydrographs to check flood risk to the site and downstream of the site.
Gauged / ungauged	There are no suitable gauges in or near the subject catchments.
Final choice of method	ReFH2.3
Key limitations / uncertainties in results	The flows in this study have been derived for the purposes of this Flood Consequence Assessment at this site using current best practice guidelines, software and data. A fuller explanation of the assumptions, limitations and uncertainties in the results from this study is given in Section 7.3

1.2 Note on flood frequencies

The frequency of a flood can be quoted in terms of a return period, which is defined as the average time between years with at least one larger flood, or as an annual exceedance probability (AEP), which is the inverse of the return period.

The table below is provided to enable quick conversion between return periods and annual exceedance probabilities.

Annual exceedance probability (AEP) and related return period reference table

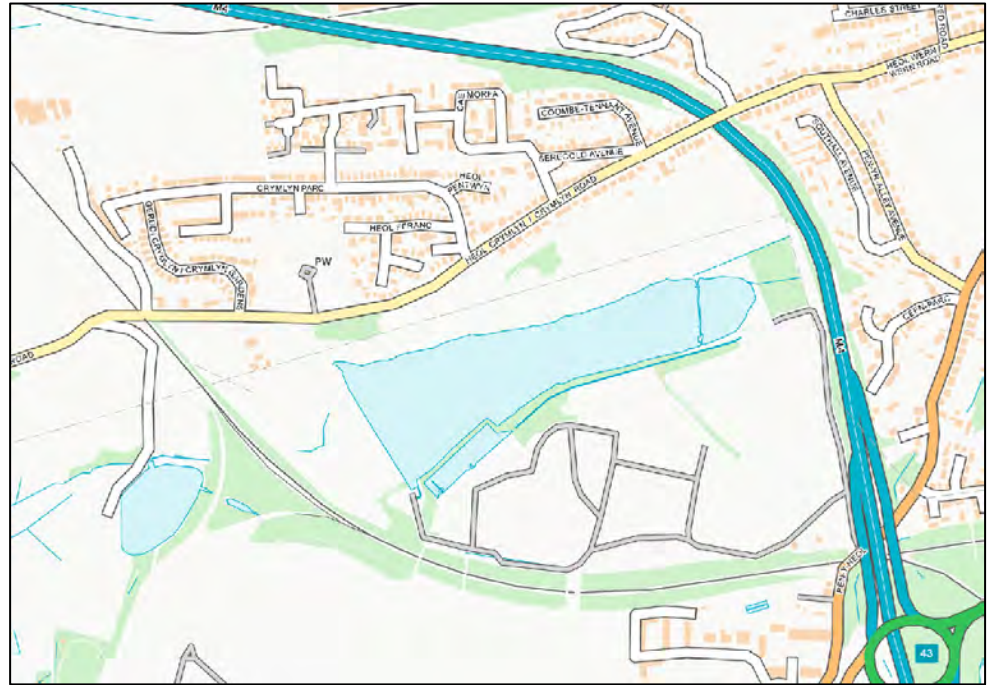
AEP (%)	50	20	10	5	3.33	2	1.33	1	0.5	0.1
AEP	0.5	0.2	0.1	0.05	0.033	0.02	0.0133	0.01	0.005	0.001
Return period (years)	2	5	10	20	30	50	75	100	200	1,000

2 METHOD STATEMENT

2.1 Requirements for flood estimates

Overview

Hydrogreen Consulting Ltd were approached by PJA Civil Engineering Ltd to undertake a hydrological analysis for a Flood Consequence Assessment at Coed Darcy, west of Neath, shown in Figure 1 below.



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Figure 1: Subject site

Inflow hydrographs were required for the model to check flood risk at the site and downstream of the site for the 1 in 30 year, 1 in 100 year, 1 in 100 year plus climate change and 1 in 1000 year return period events.

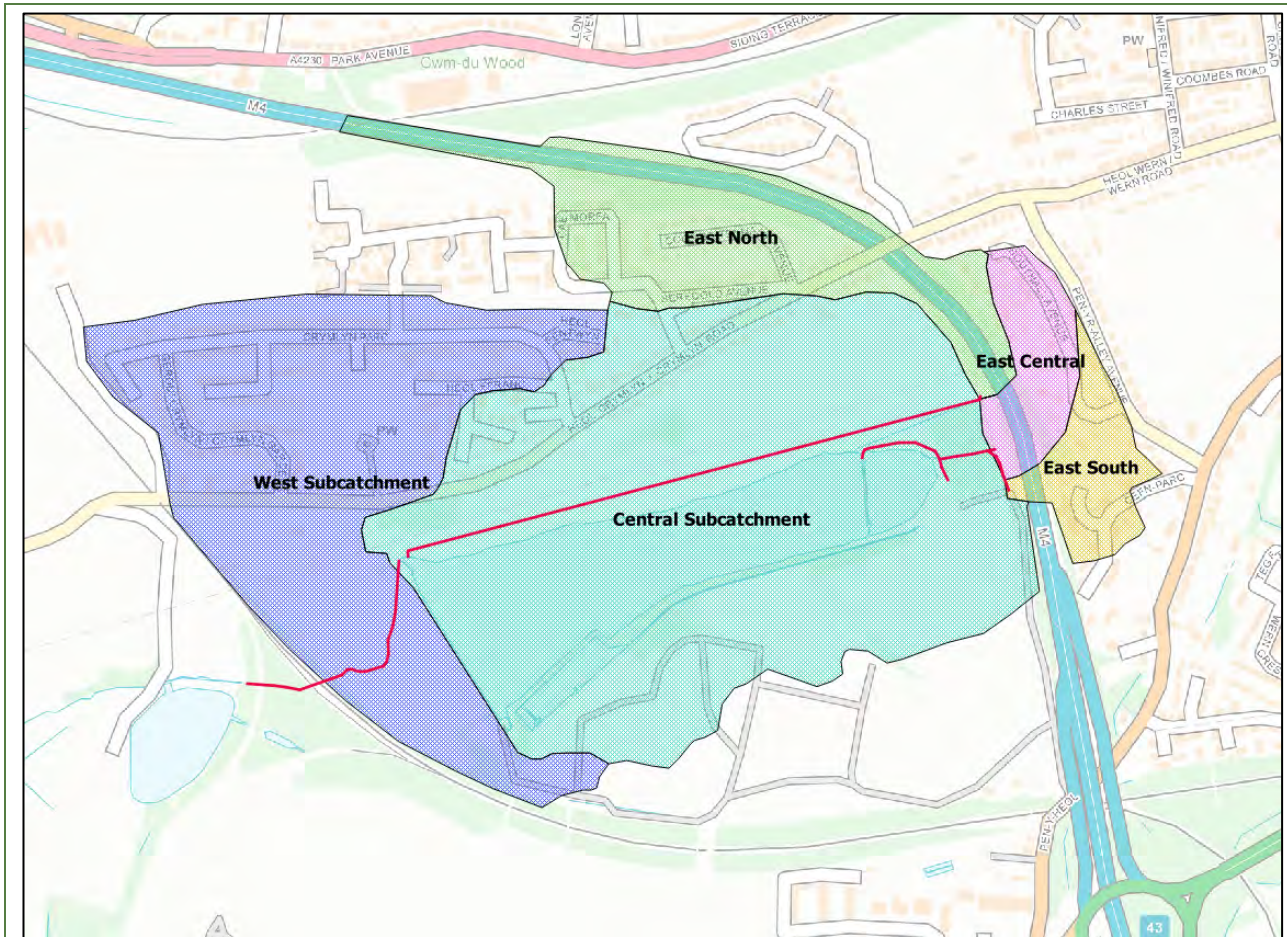
This catchment is within the West Wales River Basin District, so the Central factor / central estimate climate change allowance up to the 2080s, which is 30% on the 1 in 100 year peak river flow, will be adopted.

Project scope

There are no up-to-date hydrological analyses from previous studies available in this location, so this study has undertaken new statistical and rainfall-runoff analyses to estimate flood hydrographs for the required return periods.

The scope of this hydrological analysis is to provide inflow hydrographs to check flood risk to the site and downstream of the site. These will be used in a hydraulic model to check the difference in flood risk with and without the reservoir in place.

2.2 The catchments



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Figure 2: Catchment boundaries (colour shaded and labelled) and 1D model extents (red lines)

Description	The site is at the top of a small catchment draining south west into small watercourses which in turn drain into Swansea Bay south of the site. The catchment has been split into the subcatchments shown in Figure 2. The catchment is small, relatively steep, largely impermeable and urbanised by FEH standards. The underlying bedrock consists of the Hughes Member of sandstone which is overlain by Till superficial deposits for the south of the catchment. While there are freely draining acid loamy soils to the north and east of the catchment, the remaining majority of the catchment consists of slowly permeable seasonally wet acid loamy and clayey soils with impeded drainage. This is reflected in the relatively high value for Standard Percentage Runoff (SPRHOST) of around 46% and the correspondingly low value for Base Flow Index (BFHOST19) of 0.32.
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2.3 Source of flood peak data

Source	NRFA peak flows dataset, Version 12, released August 2023. This contains data up to and including water year 2021-22.
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2.4 Gauging stations (flow or level)

There are no useful gauges in the catchments being considered in this study.

Water-course	Station name	Gauging authority number	NRFA number	Catchment area (km ²)	Type (rated / ultrasonic / level...)	Start of record and end if station closed
N/A	N/A	N/A	N/A	N/A	N/A	N/A

2.5 Data available at each flow gauging station in Table 2.4

Station name	Start and end of NRFA flood peak record	Update for this study?	OK for QMED?	OK for pooling?	Data quality check needed?	Other comments on station and flow data quality
N/A	N/A	N/A	N/A	N/A	N/A	N/A
Give link/reference to any further data quality checks carried out			The gauges nearest to the subject catchment (within 20 km) are as follows. - Nant-y-Fendrod @ Clarion Close which is only 3.5 km away from the subject catchment but after making enquiries with Natural Resources Wales it is understood that this gauge does not have a reliable rating (it is not a NRFA gauge). - Gauge 59001 (Tawe @ Ynystanglws) which is 16.5 km away and has an upstream catchment area of around 228 km². - Gauge 58012 (Afan @ Marcroft Weir) which is around 13 km away and has an upstream catchment area of around 88 km². - Gauge 58008 (Dulais @ Cilfrew) which is also around 13 km away and has an upstream catchment area of around 43 km². The gauge at Clarion Close has no reliable rating and is therefore not suitable for use as a donor. The catchments upstream of the other gauges (59001, 58012 and 58008) are very much larger and much steeper than the subject catchment and therefore also unsuitable to use as donors.			

2.6 Rating equations

Station name	Type of rating	Rating review needed?	Comments and link to any rating reviews
N/A	N/A	N/A	N/A

2.7 Other data available and how it has been obtained

Type of data	Data relevant to this study?	Data available?	Source of data	Details
Check flow gaugings	N/A	N/A	N/A	N/A
Historical flood data	Publicly available data from Natural Resources Wales (NRW) does not indicate any historic flooding at or near the subject site. Similarly, searches of publicly available data from Neath Port Talbot County Borough Council yielded no records of historic flooding at the subject site.			
Flow or river level data for events	N/A	N/A	N/A	N/A

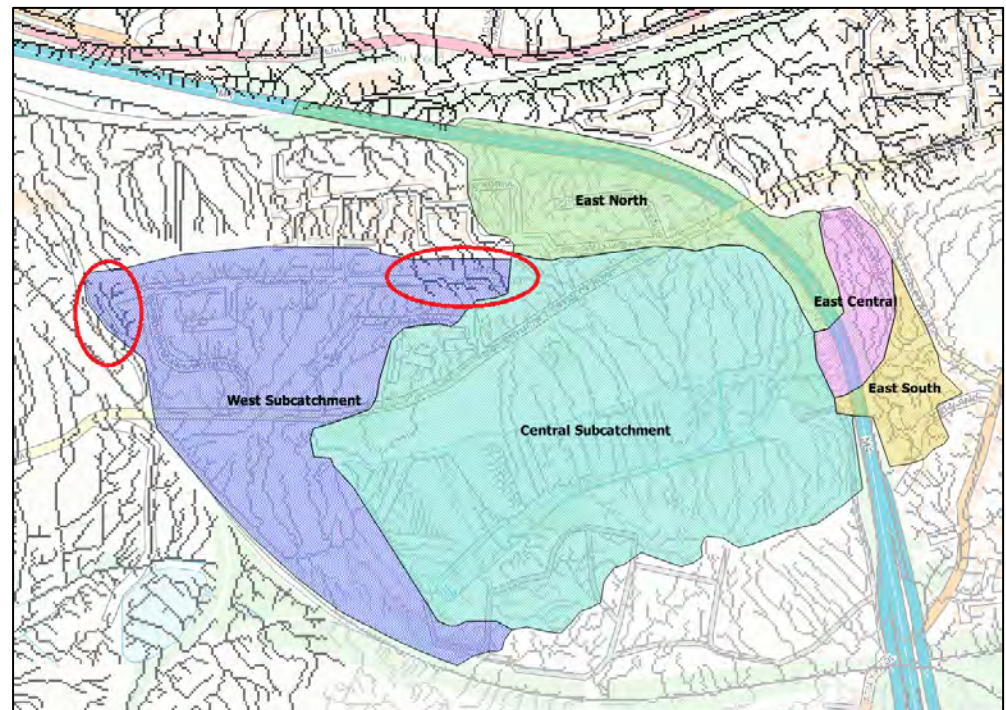
Coed Darcy FEH Calculation Record

Rainfall data for events	N/A	N/A	N/A	N/A
Potential evaporation data	N/A	N/A	N/A	N/A
Results from previous studies	N/A	N/A	N/A	N/A
Other data or information	N/A	N/A	N/A	N/A

2.8 Hydrological understanding of catchment

Conceptual model

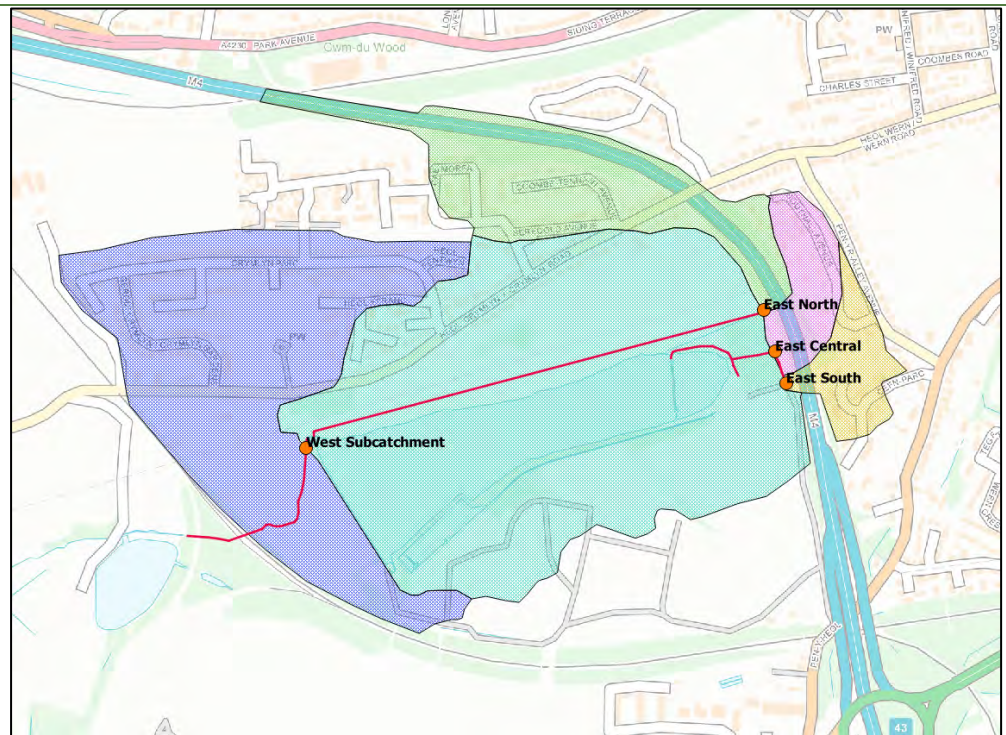
The main sources of flood risk to the site are surface water and fluvial. The scope of this hydrological analysis is to provide inflow hydrographs to the 1D-2D model to check flood risk to the site and downstream of the site. The catchment schematisation and 1D model extents are shown in Figure 2 above. The catchment was split using the surface water drainage paths calculated using the LiDAR. The sewer mapping from the water company was also checked which resulted in enlarging the West subcatchment to include small areas outside the topographic catchment that drain into the subject catchment via the sewer network. These are highlighted with the red ellipses in Figure 3 below.



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Figure 3: Drainage paths from LiDAR used to schematise catchments. Additional areas from the sewer catchments highlighted in red ellipses.

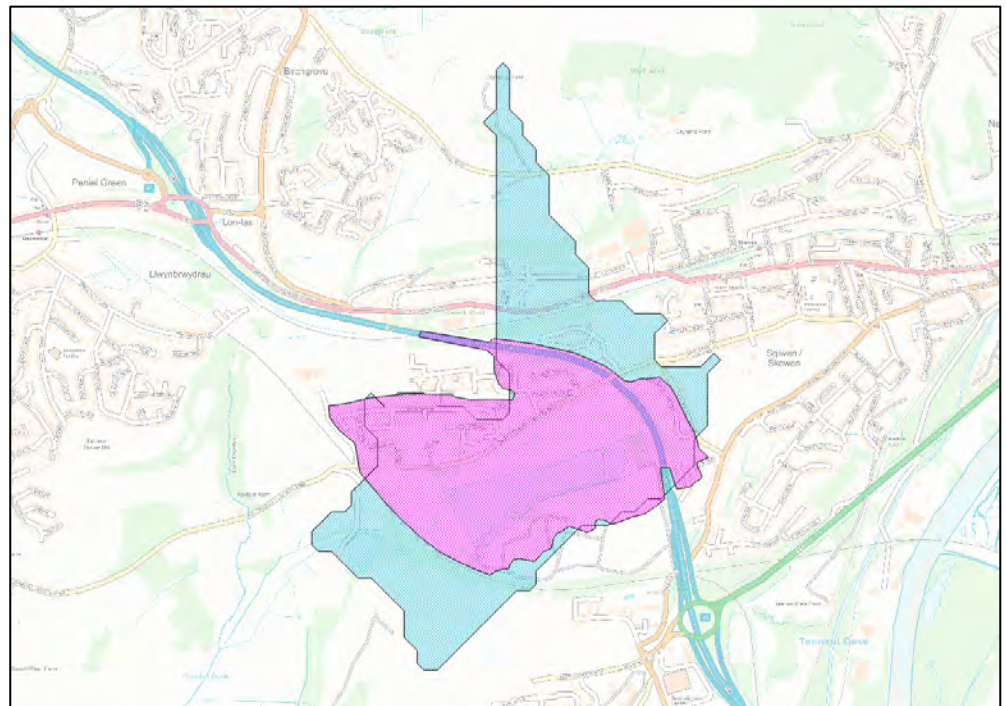
The proposed inflow points for four of the five subcatchments are shown in Figure 4 below. An area-distributed method was used for applying the inflow from the Central subcatchment to the 2D model domain.



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Figure 4: Proposed model inflow points – orange dots – the names correspond with those of the subcatchments. An area-distributed method was used for applying the inflow from the Central Subcatchment to the 2D model domain.

A comparison of the catchment boundary from the FEH web service and that derived using the latest 2022/2020 LiDAR is shown in Figure 5 below. The catchment shaded in blue from the FEH web service was used for an initial estimate of the catchment descriptors for the subject catchment. These catchment descriptors were checked and, where necessary, updated as described in Section 3 below.



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Figure 5: Comparison of the catchment boundary from the FEH web service (shaded blue) and that derived by means of the LiDAR (shaded pink)

Unusual catchment features	The subject catchment is small by FEH standards, the sum of the areas of the five topographical catchments shown in Figure 2 being only 0.75 km ² . FEH methods are not normally used for catchments smaller than 0.5 km ² .
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2.9 Initial choice of approach

Is FEH appropriate?	Yes
Initial choice of method(s) and reasons	ReFH2 and FEH statistical analyses will be undertaken for the lumped subject catchment and the peak flows compared. One of these methods will be selected for the peak flows, with the ReFH2 method being used to derive the hydrograph shapes for the inputs to the hydrodynamic hydraulic model. A separate ReFH2.3 boundary will not be used for each subcatchment since each of their areas are less than the 0.5 km² minimum area for application of FEH methods. FEH methods will therefore be applied to the lumped catchment and area-weighting used to derive flows for the subcatchments.
Software to be used (with version numbers)	FEH Web Service ¹ / WINFAP-FEH v5 ² / ReFH 2.3 / FEH22 DDF model

¹ CEH 2015. The Flood Estimation Handbook (FEH) Online Service, Centre for Ecology & Hydrology, Wallingford, UK.

² WINFAP-FEH v5 © Wallingford HydroSolutions Limited and NERC (CEH) 2021.

3 LOCATIONS WHERE FLOOD ESTIMATES REQUIRED

FEH methods were applied to the lumped catchment in order to compare the peak flows from the different FEH methods and decide which method to use for the final flows in the subject catchments.

3.1 Summary of subject sites

Site code	Watercourse	Site	Easting	Northing	AREA on FEH CD-ROM (km ²)	Revised AREA if altered (km ²)	Reasons for choosing location
Coed Darcy	Unnamed tributary of the Crymlyn Brook	Just upstream of the culvert underneath the railway	271050	196410	1.26	0.75	To identify peak flows and hydrographs at this location for the purposes of modelling flood risk

3.2 Important catchment descriptors at each subject site (incorporating any changes made)

The catchment descriptors were taken from the FEH web service. The key catchment descriptors are given in the following table. The figures that were adjusted for this hydrological analysis are shown in red font.

Site code	FARL	PROPWET	BFIHOST19	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	URBEXT 2000	FPEXT
Coed Darcy	0.696	0.52	0.324	0.86	75.1	1331	0.274	0.0714

3.3 Checking catchment descriptors

Record how catchment boundary was checked and describe any changes	The subject catchment boundaries were drawn using the 1 metre LiDAR Digital Terrain Model taken in 2020 and utilising tools in GRASS GIS.
Record how other catchment descriptors were checked and describe any changes.	DPSBAR was checked against the LiDAR and contour data. The steepness of the subject catchment is probably lower than the default value of DPSBAR from the FEH web service catchment, but the higher value from the FEH web service data was retained as a conservative estimate. BFIHOST was checked against the geological and soils data. DPLBAR was checked against the LiDAR and contour data and updated based on the updated area using equation 7.1 in FEH Volume 5 (page 68).
Source of URBEXT	URBEXT 2000 is used for both the statistical method and ReFH2 method.
Method for updating of URBEXT	The urban area for the subject catchments was taken from the up-to-date OS data using GIS tools and URBEXT2000 calculated by applying equation 5.4 on page 22 of Defra / EA R&D Technical Report FD1919/TR, March 2006.

4 STATISTICAL METHOD

4.1 Application of Statistical method

What is the purpose of applying this method?	A statistical analysis was undertaken on the Coed Darcy lumped catchment for the purposes of comparing the peak flows derived from this method with those derived using the ReFH2 method.
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4.2 Overview of estimation of QMED at each subject site

Site code	QMED (rural) from CDs (m ³ /s)	Final method	Data transfer					Urban adjust-ment factor UAF	Final estimate of QMED (m ³ /s)
			NRFA numbers for donor sites used (see 4.3)	Distance between centroids d _{ij} (km)	Suitable for QMED ?	If more than one donor			
						Weight	Weighted ave. adjustment		
Coed Darcy	0.329	CD	N/A	N/A	N/A	N/A	N/A	1.251	0.412
Are the values of QMED spatially consistent?						N/A			
Method used for urban adjustment for subject and donor sites						Kjeldsen, T.R (2010). Modelling the impact of urbanization on flood frequency relationships in the UK. Hydrology Research, Volume 41, Issue 5, 391-405. Applied using Winfap v5 software.			
Notes Methods: AM - Annual maxima; POT - Peaks over threshold; DT - Data transfer (with urban adjustment); CD - Catchment descriptors alone (with urban adjustment); BCW - Catchment descriptors and bankfull channel width (add details); LF - Low flow statistics (add details). The QMED adjustment factor A/B for each donor site is moderated using the power term, a, which is a function of the distance between the centroids of the subject catchment and the donor catchment. The final estimate of QMED is (A/B) ^a times the initial (rural) estimate from catchment descriptors. Important note on urban adjustment The method used to adjust QMED for urbanisation published in Kjeldsen (2010) in which PRUAF is calculated from BFIHOST is not correctly applied in WINFAP-FEH v3.0.003. Significant differences occur only on urban catchments that are highly permeable. This is discussed in Wallingford HydroSolutions (2016)									

4.3 Search for donor sites for QMED (if applicable)

Comment on potential donor sites	A search for suitable donors was undertaken but none were found - see Section 2.5.
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4.4 Derivation of pooling groups

See the composition of the final pooling group in the Annex (Section 8)

Name of group	Site code from whose descriptors group was derived	Subject site treated as gauged?	Changes made to default pooling group, with reasons	Weighted average L-moments
CoedDarcy_PG_v0	Coed Darcy	No	No changes made. The pooling group has a H2 value of around 2, which is low for a catchment of this size and indicates that the pooling group is quite representative of the subject catchment.	L-CV: 0.172 L-Skew: 0.279
Note: Pooling groups were derived using the revised procedures from Science Report SC050050 (2008) in Winfap version 5 software.				

4.5 Derivation of flood growth curves at subject sites

Site code	Method	If P, ESS or J, name of pooling group	Distribution used and reason for choice	Note any urban adjustment or permeable adjustment	Parameters of distribution	Growth factor for 100-year return period
Coed Darcy	P	CoedDarcy_PG_v0	GL - best fit (lowest absolute Z value of 0.14) and recommended for UK catchments	Urban adjustment using Kjeldsen 2010 method	Location: 1.000 Scale: 0.164 Shape: -0.279	2.53
Notes Methods: SS - Single site; P - Pooled; ESS - Enhanced single site; J - Joint analysis Urban adjustments are all carried out using the method of Kjeldsen (2010). Growth curves were derived using the procedures from Science Report SC050050 (2008).						

4.6 Flood estimates from the statistical method

Site code	Flood peak (m ³ /s) for the following return periods (in years)			
	2	30	100	1000 ³
Coed Darcy	0.41	0.79	1.04	1.83

³ The statistical 1 in 1000 year peak flow estimation is projected beyond the data available in the pooling group and is given here for comparison purposes only.

5 REVITALISED FLOOD HYDROGRAPH (REFH) METHOD

The ReFH2 method was used instead of the ReFH method since the ReFH2 model is considered to outperform its predecessor (now often referred to as ReFH1) in the following ways.

- ReFH2 considers the impact of catchment urbanisation explicitly.
- ReFH2 using the FEH13 and FEH22 DDF models is physically based and does not require the 'alpha' factor to 'correct' the initial conditions in the rainfall model.
- Research reported in the ReFH2 Technical Guidance indicates that QMED estimates using the ReFH2 model on the catchments selected was closer to the observed flows than ReFH1, particularly in permeable catchments.

6 REVITALISED FLOOD HYDROGRAPH 2 (REFH2) METHOD

6.1 Application of ReFH2 method

What is the purpose of applying this method?	The ReFH2 method was applied: - to derive hydrograph shapes; - to derive the 1 in 1000 year peak flow; - for comparison purposes with the FEH statistical method to help in deciding the preferred method for determining flood peaks.
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6.2 Catchment sub-divisions for ReFH2 model

A lumped catchment approach was applied to the lumped Coed Darcy catchment for comparison with the FEH statistical method.

6.3 Parameters for ReFH2 model

Site code	Method	T _p _{rural} (hours)	T _p scaling factor	C _{max} (mm)	PR _{imp}	BL (hours)	BR
Coed Darcy	CD	1	1	236	70	20.5	0.65
Brief description of any flood event analysis carried out			N/A				
Methods: OPT: Optimisation, BR: Baseflow recession fitting, CD: Catchment descriptors, DT: Data transfer (give details)							

6.4 Design events for ReFH2 method: lumped catchments

Site code	Season of design event	Storm duration (hours)	Storm area for ARF (km ²) (if not catchment area)	Reason for selecting storm
Coed Darcy	Winter	3.75	-	Critical storm duration as tested in the ReFH2.3 software
Results of storm duration testing.		The 3.75 hour storm duration was found to be the critical one for the 1 in 100 year design scenario for the Coed Darcy catchment so this was used in the final flows for the subject catchments given in Section 7.5.		

6.5 Flood estimates from the ReFH2 method

Site code	Flood peak (m ³ /s) for the following return periods (in years)			
	2	30	100	1000
Coed Darcy	1.07	2.04	2.50	3.68

7 DISCUSSION AND SUMMARY OF RESULTS

7.1 Comparison of results from different methods

Site code	Peak flows					
	Return period 2 years / 50% AEP			Return period 100 years / 1% AEP		
	ReFH2	FEH-stat	Other method	ReFH2	FEH-stat	Other method
Coed Darcy	1.07	0.41	N/A	2.50	1.04	N/A

7.2 Final choice of method

Choice of method and reasons	The peak flows from the ReFH2 method are more than twice as large as those from the FEH statistical. The ReFH2 method was selected for the derivation of peak flows since it is based on the physical characteristics of the catchment itself. The relatively low values of peak flow from the statistical method are probably primarily due to the very low value of FARL (Flood Attenuation due to Reservoirs and Lakes) for the FEH web service catchment due to the presence of the large reservoir. The ReFH2 method does not use FARL in calculating flows. The purpose of this study is to model the difference in flood risk with and without the reservoir in place using a hydraulic model, and therefore the ReFH2 method which does not use FARL is the more appropriate one to use for this catchment.
How will the flows be applied to a hydraulic model?	Inflow hydrographs were derived in the ReFH2.3 software for the Coed Darcy catchment. These were then area-weighted between the various catchments shown in Figure 2 to derive the final model inflow hydrographs. These were applied to the hydraulic model at the inflow points shown in Figure 4. A separate ReFH2.3 boundary was not used for each subcatchment since each of their areas were less than the 0.5 km ² minimum area for application of FEH methods. FEH methods were therefore applied to the lumped catchment and area-weighting used to derive flows for the subcatchments.

7.3 Assumptions, limitations and uncertainty

List the main assumptions made (specific to this study)	The FEH catchment descriptors were taken from the nearest catchment in the FEH web service. Inspection of geological and soil data showed that the FEH web service catchment is similar to the subject catchment in terms of soils, geology and land use. Although the FEH catchment appears to be steeper than the subject catchment, the DPSBAR from the FEH web service catchment has been adopted as a conservative approach.
Discuss any particular limitations	The relatively low values of peak flow from the statistical method are probably primarily due to the very low value of FARL (Flood Attenuation due to Reservoirs and Lakes) for the FEH web service catchment due to the presence of the large reservoir. Since the impact of the storage in the reservoir is being modelled hydraulically, the ReFH2 method is more appropriate for use in this study. The FEH statistical method was used to derive a peak flow for the 1 in 1000 year return period for the purposes of comparison with ReFH2, although the pooling group only had 500 years of data and therefore should not normally be used for deriving flows greater than a 1 in 100 year return period.

Provide information on the uncertainty in the design peak flow estimates and the methodology used	There are no published methods for calculating uncertainties and confidence intervals for the ReFH2 model. In practice the uncertainties and confidence intervals will depend upon a number of factors. However, a UK average measure for the 95% confidence limits for a 1 in 100 year event was produced in 2014 (Kjeldsen) as follows: - 0.45 to 2.25 times the best estimate (with donor adjustment); and - 0.42 to 2.37 times the best estimate (without donor adjustment). A more recently published report (EA, CEH, JBA) provided the not-dissimilar 95% confidence intervals as follows. These are the figures used for calculation of the 1 in 100 year confidence intervals in Section 7.6. <table><tr><th>Return period (1 in X years)</th><th>With donor</th><th>Without donor</th></tr><tr><td>2</td><td>0.5 to 2.02</td><td>0.48 to 2.1</td></tr><tr><td>100</td><td>0.47 to 2.12</td><td>0.45 to 2.23</td></tr></table>	Return period (1 in X years)	With donor	Without donor	2	0.5 to 2.02	0.48 to 2.1	100	0.47 to 2.12	0.45 to 2.23
Return period (1 in X years)	With donor	Without donor								
2	0.5 to 2.02	0.48 to 2.1								
100	0.47 to 2.12	0.45 to 2.23								
Comment on the suitability of the results for future studies	The flows in this study have been derived for the purposes of this Flood Consequence Assessment for this site using current best practice guidelines, software and data; the hydrology should be reviewed prior to being applied for any future purposes.									
Give any other comments on the study	Monitoring flows and levels in the modelled watercourses in this study would reduce uncertainties in future flood estimates.									

7.4 Checks

Are the results consistent, for example at confluences?	Yes, the flows derived are broadly proportional to the catchment sizes.
What do the results imply regarding the return periods / frequency of floods during the period of record?	There are no gauges or gauged data available.
What is the range of 100-year / 1% AEP growth factors? Is this realistic?	The 1 in 100 growth factor for the combined fluvial catchments using the ReFH2.3 method is 2.3. This falls within the 2.1 to 4.0 range of 1 in 100 year growth factors in the Flood Studies Report and is reasonable for a Welsh lowland catchment.
If 1000-year / 0.1% AEP flows have been derived, what is the range of ratios for 1000-year / 0.1% AEP flow over 100-year / 1% AEP flow?	The 1 in 1000 year to 1 in 100 year peak flow ratio for the combined fluvial catchments using the ReFH2.3 method is 1.5.
What range of specific runoffs (l/s/ha) do the results equate to? Are there any inconsistencies?	The specific runoff values for these small catchments in the baseline scenario for the 1 in 100 year event are all in the region of 33 l/s/ha.
How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred.	N/A
Are the results compatible with the longer-term flood history?	N/A
Describe any other checks on the results	The results from the hydraulic model are reasonable when compared with the existing published flood outlines in this area.

7.5 Final results

Subcatchment (see Fig 2)	Subcatchment Area	Peak flow (m ³ /s) for the following return periods (1 in X years)				
	(Km ²)	2	30	100	100 +30% CC	1000
East North	0.10	0.14	0.28	0.34	0.44	0.50
East Central	0.03	0.04	0.08	0.09	0.12	0.14
East South	0.03	0.04	0.08	0.09	0.12	0.14
Central Subcatchment	0.38	0.54	1.03	1.26	1.63	1.85
West Subcatchment	0.22	0.31	0.59	0.72	0.93	1.06

7.6 Uncertainty bounds

This table reports the 95% confidence interval flows for the peak flows. The 'true' value is more likely to be nearer the estimate reported in Section 7.5 above than the bounds. However, it is possible that the 'true' value could still lie outside these bounds.

1 in 100 year 95% Confidence intervals	Peak flow in m ³ /s	
	Lower	Upper
East North	0.15	0.75
East Central	0.04	0.21
East South	0.04	0.21
Central Subcatchment	0.57	2.80
West Subcatchment	0.32	1.60

8 ANNEX

The final pooling group composition for the Netherton catchment is follows.

Station	Distance (SDM)	Years of data	QMED AM	L-CV Observed	L-SKEW Observed	Discordancy
76011 (Coal Burn @ Coalburn)	0.831	45	1.84	0.171	0.292	0.344
45816 (Haddeo @ Upton)	1.769	29	3.248	0.289	0.432	1.979
28033 (Dove @ Hollinsclough)	1.868	47	4.15	0.231	0.381	0.85
25011 (Langdon Beck @ Langdon)	2.263	36	15.878	0.223	0.321	0.375
27051 (Crimple @ Burn Bridge)	2.278	50	4.641	0.218	0.133	0.391
47022 (Tory Brook @ Newnham Park)	2.291	27	6.176	0.246	0.151	0.696
71003 (Croasdale Beck @ Croasdale Flume)	2.329	37	10.9	0.212	0.323	0.29
25003 (Trout Beck @ Moor House)	2.388	49	15.12	0.165	0.298	0.504
106002 (Laxdale @ Laxdale)	2.399	15	17.224	0.093	0.131	1.724
206006 (Annalong @ Recorder)	2.448	48	15.33	0.189	0.052	1.793
49005 (Bolingey Stream @ Bolingey Cocks Bridge)	2.526	12	4.924	0.266	0.268	2.419
91802 (Allt Leachdach @ Intake)	2.536	34	6.35	0.153	0.257	0.685
27073 (Brompton Beck @ Snainton Ings)	2.574	42	0.816	0.212	0.02	1.358
54022 (Severn @ Plynlimon flume)	2.641	38	14.988	0.156	0.171	0.591

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