Felin Puleston Weir

Optioneering

DRAFT Report

Welsh Dee Trust

Quality information

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Felin Puleston Weir Optioneering and Design DRAFT Report v1.0	Seb Bentley and Rob Williamson	11th November 2022	George Heritage	George Heritage

Contents

Glossary

Terminology	**Meaning**
2D modelling	Two-dimensional hydraulic modelling
Bed shear stress	Measure of the force exerted by moving water on the river bed
Bedload transport	Process of movement of sediment along the bed of a watercourse
Geomorphology	The study of the physical features of the surface of the earth and associated processes
Hydromorphology	The physical character and water content of water bodies
LIDAR	Light Detection and Ranging Data (provides a topographical surface)
Sediment transport	Process of movement of sediment along a watercourse

1 Introduction and Methodology

1.1 Background and Objectives

The Welsh Dee Trust commissioned Dynamic Rivers to undertake the optioneering and design for providing fish passage and improving the geomorphological functioning for a weir on the Afon Clywedog to the south west of Wrexham at Felin Puleston, located on land owned by the National Trust (Figure 1.1).

Figure 1.1. Felin Puleston Weir location (image provided by the client).

1.2 Approach

We have gained a detailed understanding of the state, activity and sensitivity of the watercourse along the study reach influenced by the weir, through the review of LiDAR data (DTM and DSM) archival maps and aerial photography illustrating system functioning over both historical and recent time. This was combined with a targeted walkover that helped confirm information identified during the desk study, identifying flow and sediment sources and sinks, geomorphological units and geomorphological processes linked to the sediment transport. These data were linked to the likely channel change regime. All data were reviewed against the initial hydraulic modelling outputs.

We have also reviewed potential natural and artificial constraints to the proposed works and the walkover and desk study findings have been used to identify options from a fish passage and geomorphological processes perspective. No structural stability or engineering assessments have been made as part of this study. Options were shared with the client and steering group to allow selection of the preferred weir and restoration measures to take forward to detailed hydraulic modelling and production of the detailed design.

We have quantified the geomorphological and flood risk impacts of the preferred weir option for the Felin Puleston weir and impacted reach of the Afon Clywedog, using a 2D hydraulic model (HEC-RAS) for the river, utilising information including NRW LiDAR and additional dGPS survey. The 2D modelling approach has been applied across both the river and surrounding valley bottom allowing inundation areas to be mapped. Data from the flow modelling across the flow regime in the form of shear stress was used to confirm impacts to the flow and sediment regime and the model flow record was used to determine impacts on the flood hydrograph downstream by monitoring the flow at the end of the model and comparing it to the baseline outputs.

2 Fluvial Audit

2.1 Desk and Field Based Assessment

The Afon Clywedog may be classified as a steep, modified, alluvial single thread channel through the study reach at Felin Puleston. It has been modified from its natural state and constrained as a single-thread channel, mainly as a result of bank protection works upstream of the weir in the form of gabion baskets. These are in a poor state, as described in the field audit section below. Modifications to the planform of the watercourse predate the earliest available OS maps, with Figure 2.1 showing historic channel straightening and creation of in-channel structures associated to a series of Mills along the reach, with a corn mill being located just upstream of the current weir together with an associated mill race over the left-hand bank. The watercourse appears to have begun to reform a more natural planform downstream of the weir structure, with a series of meanders developing since the straightening pre-1879. This is demonstrated in the Google Earth imagery shown in Figure 2.2 below where development of these bends and associated gravel morphology is clear together with potential attempts to restrict the movement and protect the nearby footpath (which is also considered in the options development for this scheme local to the weir) in 2018. This demonstrates the active nature of the river and highlights the potential for significant lateral erosion and response along the study reach. Figure 2.2 shows the presence of trees over both banks upstream of the weir, masking the channel itself, however there is also a footbridge linked to the path shown that spans across the Afon Clywedog.

Figure 2.1. Comparison of 1879 historic map and current mapping for the Afon Clywedog study reach.

Figure 2.2. Meander bend development on the Afon Clywedog downstream of Felin Puleston weir (copyright Google Earth).

The present watercourse flows mostly over river alluvium (Figure 2.3) along the study reach, with a belt of alluvium around the weir and upstream indicating a wider historic floodplain. Use of this floodplain by the present river has been significantly constrained by development and modification over time. This is demonstrated by the Flood Map for Planning (Figure 2.5), showing a much more constrained Flood Zone 3, highlighting the significant modification to the floodplain and disconnectivity. The alluvial deposits overlay the Etruria Formation Mudstone (Figure 2.4). This bedrock is not significantly exposed along the study reach. The dominant control on the current river processes is the alluvium layer that is being reworked across a limited area, as demonstrated by Figure 2.2.

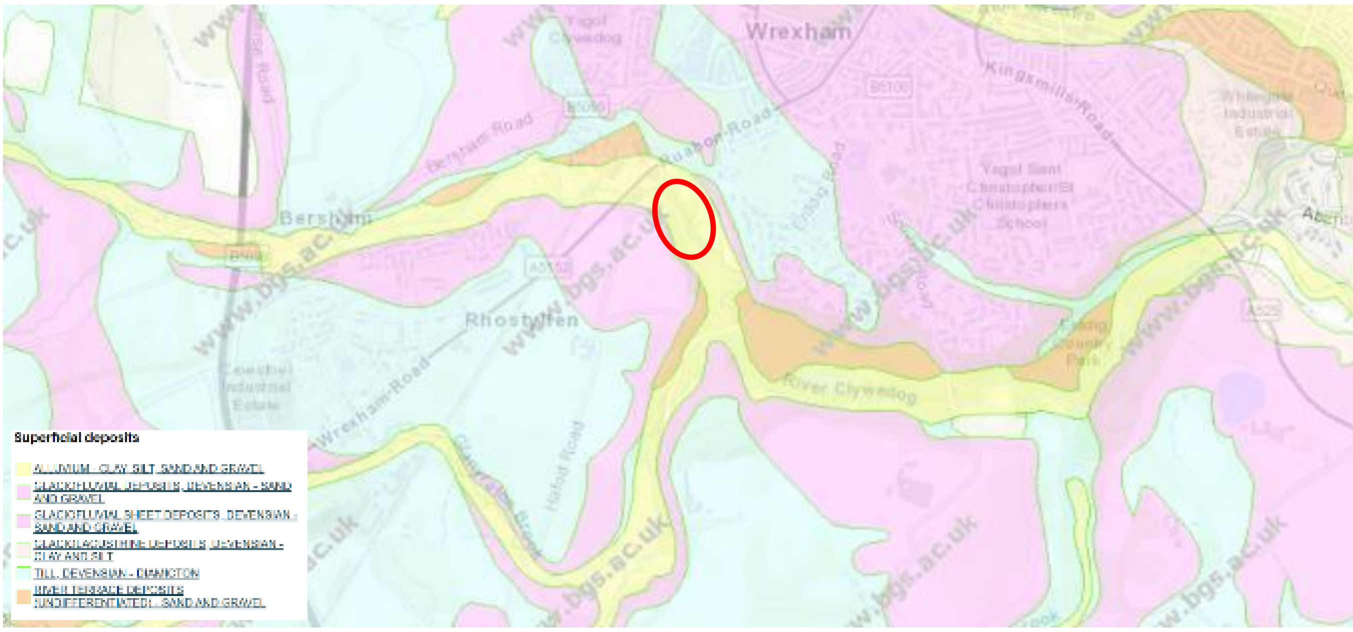


Figure 2.3. Drift geology of the Afon Clywedog study reach

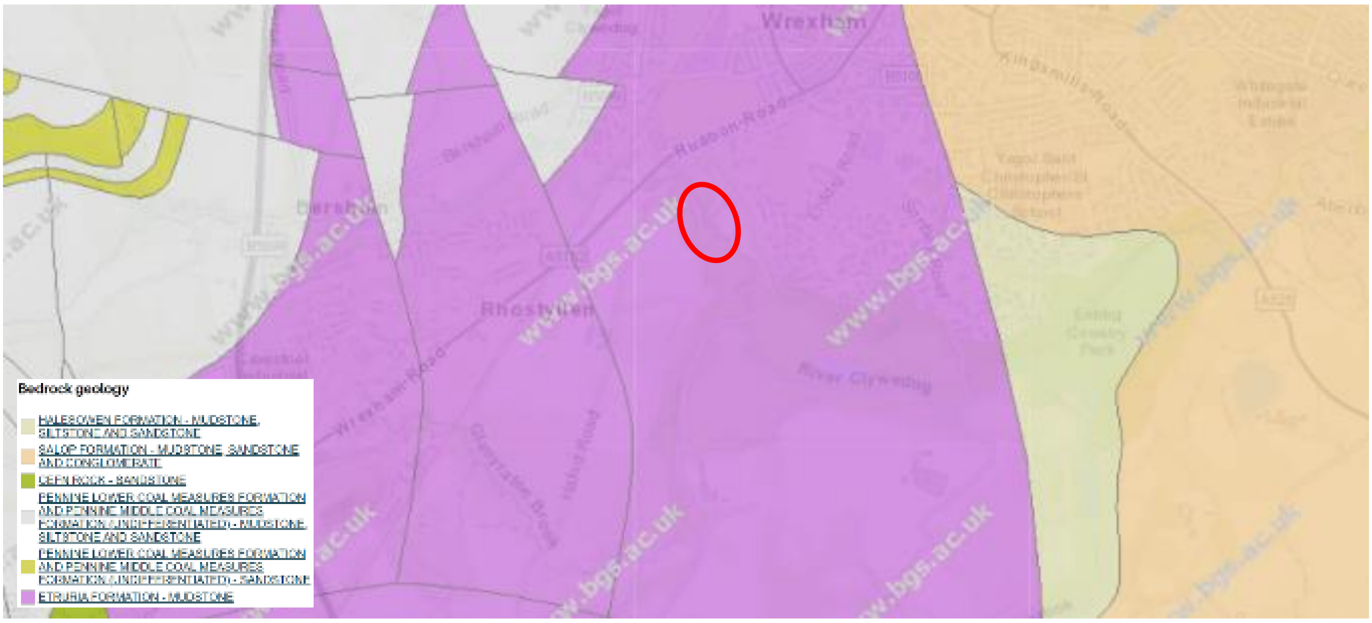


Figure 2.4. Bedrock geology of the Afon Clywedog study reach

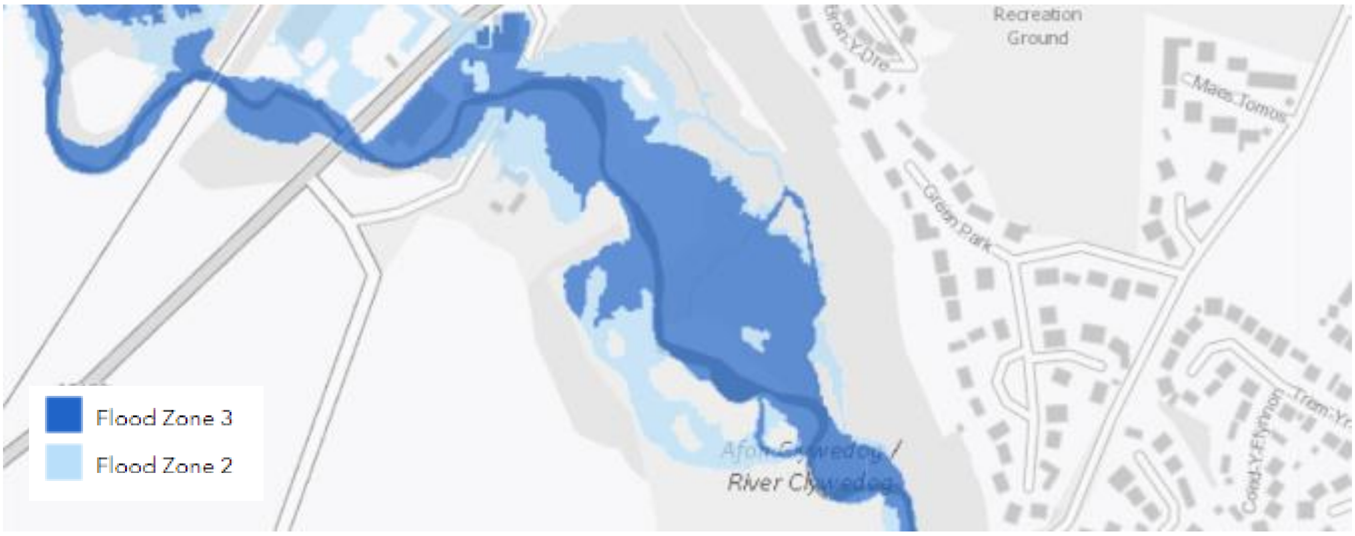


Figure 2.5. Flood map for planning along the study reach showing the extent of Flood Zones 2 and 3

2.1.1 Flow Regime

The steepness of the Afon Clywedog reach and surrounding urbanisation and associated bank protection works, has created flow conditions that are flashy, where there is a steep rise to the peak during flood events as a result of flow concentration in the channel and the steep gradient. Whilst flows are not gauged locally on the Afon Clywedog, Figure 2.6 below shows the gauge record for the Clywedog at Bowling Bank gauge further downstream. This demonstrates the relatively steep rise to peak during elevated flows. Whilst not surprising given the gradient, modification and surrounding land use, this demonstrates the high energy flows that occur along the study reach, providing the forces necessary to rework alluvial material and damage surrounding infrastructure, such as the gabion baskets along the left bank edge upstream of the weir. This is also considered in the options development phase of this study for weir modification etc.

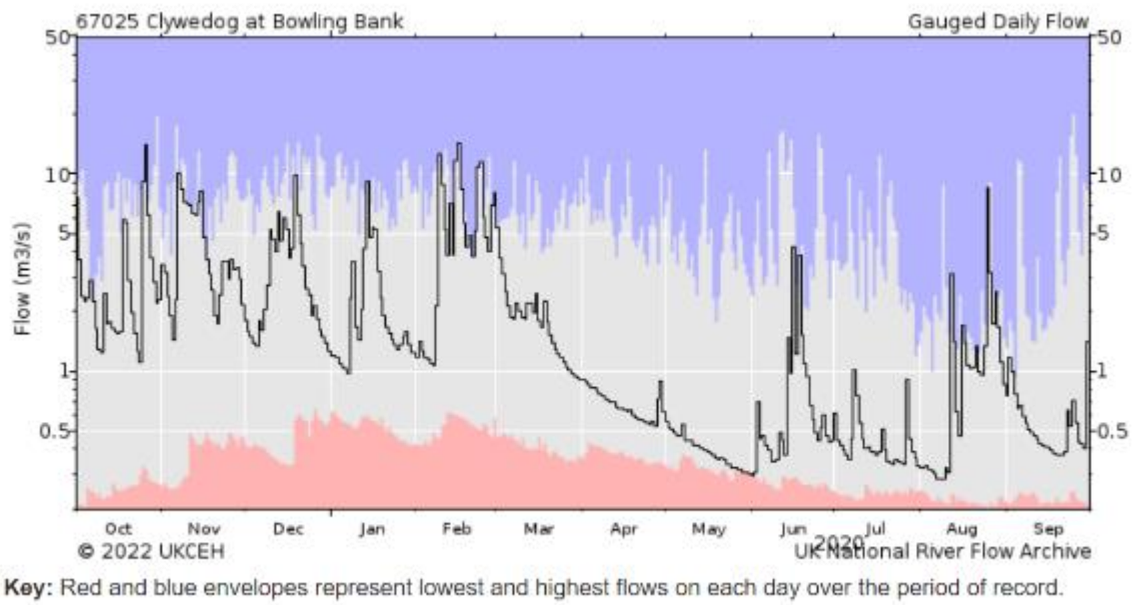


Figure 2.6. Flow record for the Clywedog at Bowling Bank gauge (source: nfra)

Overall, the desk study suggests a high energy, flashy, modified river channel flowing over Holocene alluvium. There is clear evidence of historic straightening and in-channel structures are present linked to earlier industrialisation and mill operation. Detail on sediment character, sediment transport and channel and floodplain dynamics are discussed further in the field audit section below.

2.2 Field Study

The fluvial audit undertaken for the purposes of this project found that the watercourse has been subject to significant historic modification as identified in the desk study, through channel realignment/straightening and works to the river bank upstream in the form of gabion baskets. There are numerous structures along the Afon Clywedog study reach (footbridge, services, bank protection), with the weir in question providing an obstacle to fish passage under summer/winter flow conditions. The weir is located downstream of a footbridge and within land owned by the National Trust. There is a wooded riparian corridor upstream, opening out further downstream with a footpath running over the right-hand bank.

The weir provides a head difference of approximately 1m under summer/winter flow conditions across the structure (Figure 2.7). There are recent repairs to the weir over both banks, with gabion baskets present over the left-hand bank immediately downstream (Figure 2.7 and 2.8). These also appear to be in a poor state. The weir appears to be composed of concrete forming a three-step structure. Erosion issues in the vicinity of the weir remain and are continuing as a result of high energy flows and the influence of the weir structure (Figure 2.9). Continued repairs are likely to be required to mitigate against failure or outflanking of the structure with or without any restoration works. The weir is no longer interrupting transport of gravels and cobbles downstream, with dynamic gravel features evident approximately 200m downstream (Figure 2.2), this is unsurprising given the steep gradient, flashy flows and the likelihood that the weir is drowned out during flood flows when material is being transported.

Figure 2.7. Weir structure showing three step concrete construction

Figure 2.8. View of weir from left bank also showing leaning gabion basket repairs

Figure 2.9. Erosion of the right bank immediately downstream of the weir structure

Bank protection upstream of the weir along the reach is also in a varying state of disrepair with some walling and gabion baskets requiring attention evident on site (Figure 2.10 and 2.11). The structure does not impound a significant distance upstream due to the steep gradient along the study reach. There is some stored sediment behind the weir as a result of the impounding influence with riffle-rapid features evident not far upstream of the weir (Figure 2.12). These and other transverse bar features are common through the reach (Figure 2.13 and 2.14) and are composed of mobile gravel and cobble material.

Figure 2.10. Failing gabion basket bank protection upstream of the weir at Felin Puleston adjacent to Wrexham Tyres Warehouse and the A5152 bridge

Figure 2.11. Failing walling just downstream of the footbridge

Figure 2.12. View from footbridge downstream showing flow dynamics across riffle-rapid features

Figure 2.13. Transverse bar development showing gravel/cobble composition

Figure 2.14. Bar development showing gravel/cobble composition along the study reach upstream of the weir

A footbridge crosses the river approximately 95m upstream of the weir structure, with evidence of services also crossing the river at this location (Figure 2.15, see Figure 3.14 for further services information).

Figure 2.15. Service crossing the river along downstream face of footbridge

2.3 Summary

In summary, the Afon Clywedog is a high energy, flashy, modified river channel flowing over Holocene alluvium. There is clear evidence of historic straightening and in-channel structures are present linked to earlier industrialisation and mill operation. Surrounding hard engineering is currently failing, independent of the influence of the weir and there is ongoing erosion pressures around the weir structure itself. The steep gradient and flashy flow regime contribute to high energy conditions along the reach during flood flows that are capable of transport gravel and cobble sized material. The weir itself is a complete obstacle to fish passage and risks failure in the medium to long term which will exacerbate stability issues elsewhere.

Various options for providing fish passage across the structure have been appraised in section 3 below.

3 Optioneering and Modelling

3.1 Optioneering – Felin Puleston Weir

Following the audit and preliminary flow modelling, several options were considered for the Felin Puleston Weir on the Afon Clywedog to provide fish passage at the structure and to improve the hydromorphological functioning. These are described in the following sections.

3.1.1 Option 1 - Full removal of the weir structure

Under this scenario, the weir would be removed in full with no associated regrading of the river bed upstream and downstream, see Figure 3.1 (effectively demonstrating a complete failure of the weir). The river would quickly respond to the new hydraulic conditions, incising upstream as a result of the knickpoint created where the weir is removed and the flow allowed to cascade into the downstream weir. This could have significant impacts to infrastructure upstream and is therefore rejected on this basis.

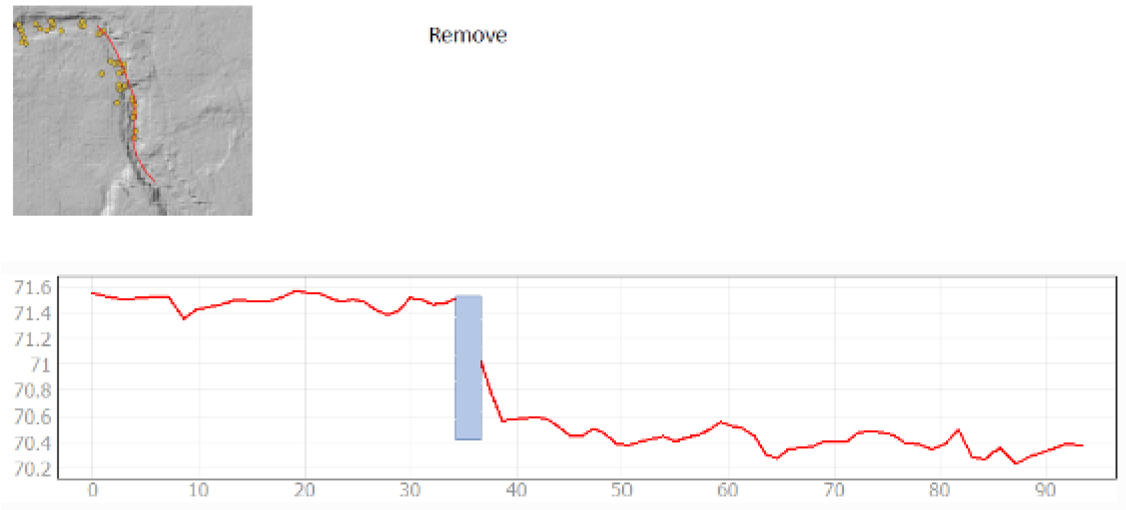


Figure 3.1. Full weir removal concept for Felin Puleston weir.

3.1.2 Option 2 - Full removal of the weir structure and bed regrading

Under this scenario, the weir would be removed in full and regrading of the river bed upstream and downstream would be undertaken to provide a smooth bed profile, this would include infilling of the weir pool immediately downstream, see Figure 3.2. The steep gradient created could instigate vertical and lateral erosion and the impact of this option on hydraulics has been considered in the initial modelling described in section 3.5 and 3.6 below.

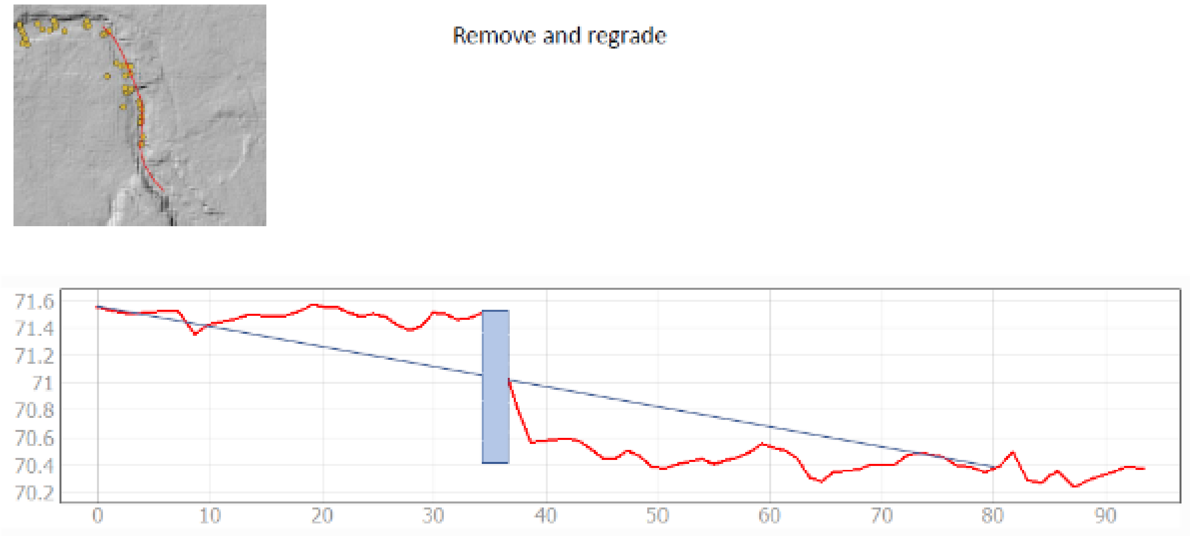


Figure 3.2. Full weir removal and bed regrading concept for Felin Puleston weir.

3.1.3 Option 3 - Full removal of the weir structure and bed regrading with feature introduction

Under this scenario, the weir would be removed in full and regrading of the river bed upstream and downstream would be undertaken using a series of riffle-rapid features to attempt to control the released hydraulic gradient following removal of the weir, see Figure 3.3. The steep gradient created, would likely cause significant lateral and vertical instability despite the use of features as these would not be high enough to provide a suitable control on the upstream hydraulics. Therefore, this option is rejected on this basis.

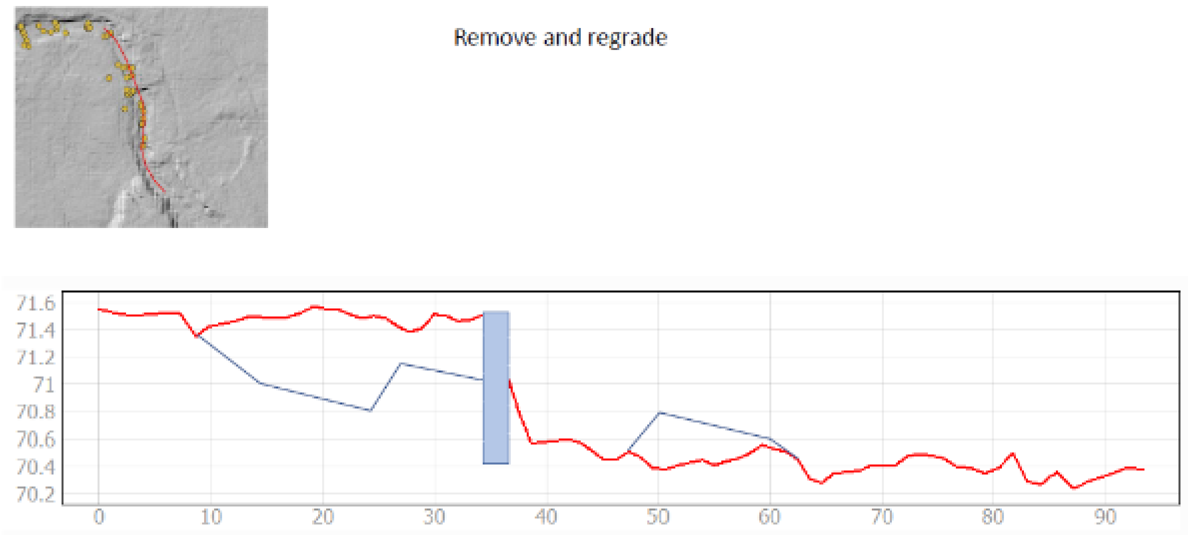
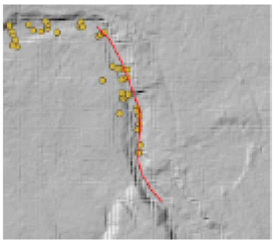


Figure 3.3. Full weir removal and bed regrading with feature introduction concept for Felin Puleston weir.

3.1.4 Option 4 - Retain weir and drown out using riffle-rapid features

Under this scenario, the weir would be retained at its current height and a series of riffle-rapid features would be constructed downstream of the structure to raise the water levels to the height of the weir to allow fish passage for most fish across the structure. The hydraulic gradient is then controlled by the series of features extending downstream from the weir with deep pools forming in between each feature that would also provide refuge for fish. These features naturally form along the Afon Clywedog so would not be out of place from a hydromorphological perspective. This is demonstrated in Figure 3.4. This option has not been considered in the initial modelling as the riffle-rapid features would be large, the lowering weir option described below is preferable in this respect.



Retain and drown out

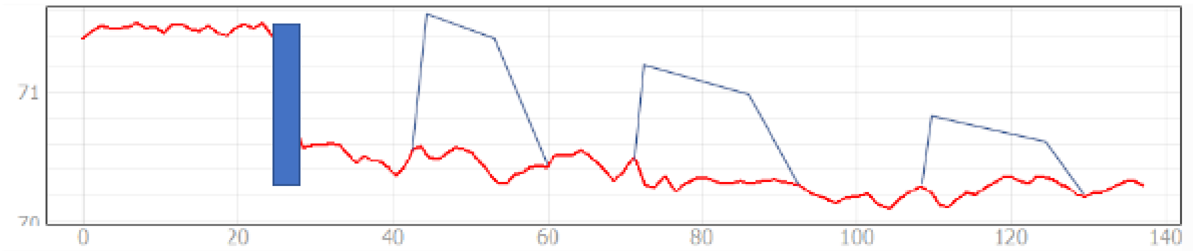


Figure 3.4. Retain weir and drown out using riffle-rapid features introduction concept for Felin Puleston weir.

3.1.5 Option 5 - Lower weir and drown out using riffle-rapid features

Under this scenario, the weir would be lowered across its width and a series of riffle-rapid features would be constructed downstream of the structure to raise the water levels above the height of the lowered weir to allow fish passage for most fish species. The remaining weir may require stabilisation following any lowering. The hydraulic gradient is then controlled by the series of features extending downstream from the lowered weir with pools forming in between each feature that would also provide refuge for fish. These features naturally form along the Afon Clywedog so would not be out of place from a hydromorphological perspective. This is demonstrated in Figure 3.5. This option is feasible for the Felin Puleston weir and has been considered in the initial modelling described in section 3.5 and 3.6 below.

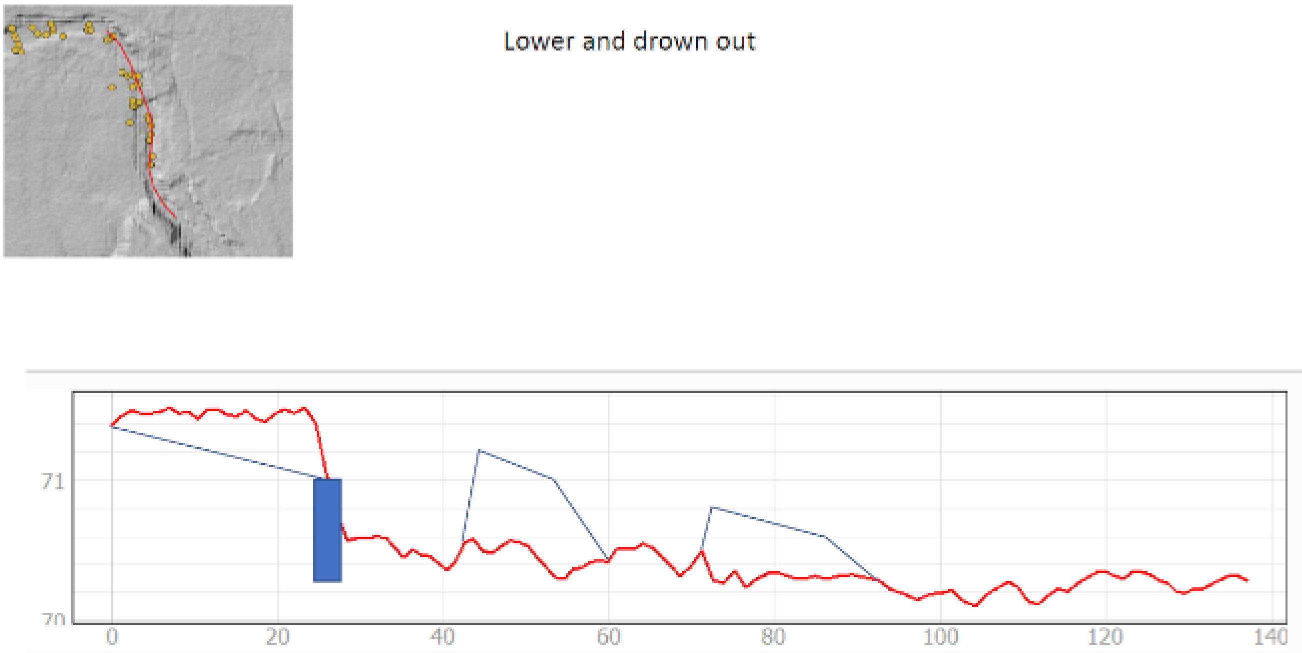


Figure 3.5. Lower weir and drown out using riffle-rapid features introduction concept for Felin Puleston weir.

3.1.6 Option 6 - Bypass channel around weir over right bank

Under this scenario, the weir would be bypassed through creation of a bypass channel over the right-hand bank around the structure over an approximate ~130m length, tying into upstream and downstream bed levels at the connection points. This bypass channel would be steep and laterally active but would provide a passage for most fish. The current channel could be retained to retain flood capacity but ongoing maintenance of the remaining weir structure is likely. The option is demonstrated below in Figure 3.6 and has been considered in the initial modelling described in section 3.5 and 3.6 below.

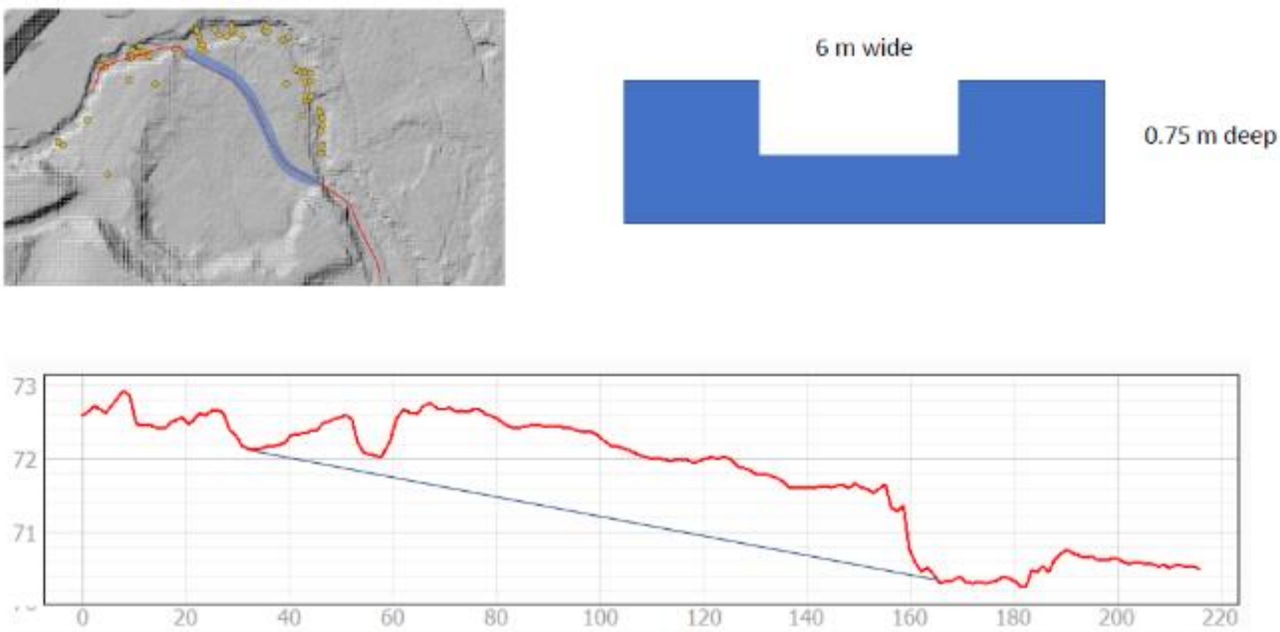


Figure 3.6. Bypass channel around weir over right bank concept for Felin Puleston weir.

3.1.7 Option 7 - Creation of inset berm over right bank

Under this scenario, the weir would be removed and the whole right bank floodplain area indicated in Figure 3.7 would be lowered and existing channel regraded to create a large area over which flow could disperse and flow over. This would reduce the flow energy over a wider area in comparison to the single bypass channel option described above. The area would still be active with new channels being cut naturally over time and associated deposition in response to flood flows. This option would provide passage for most fish. This feature is over a similar length to the bypass channel and has a variable width, tying into upstream and downstream bed levels at the connection points. The option is demonstrated below in Figure 3.7 and has been considered in the initial modelling described in section 3.5 and 3.6 below.

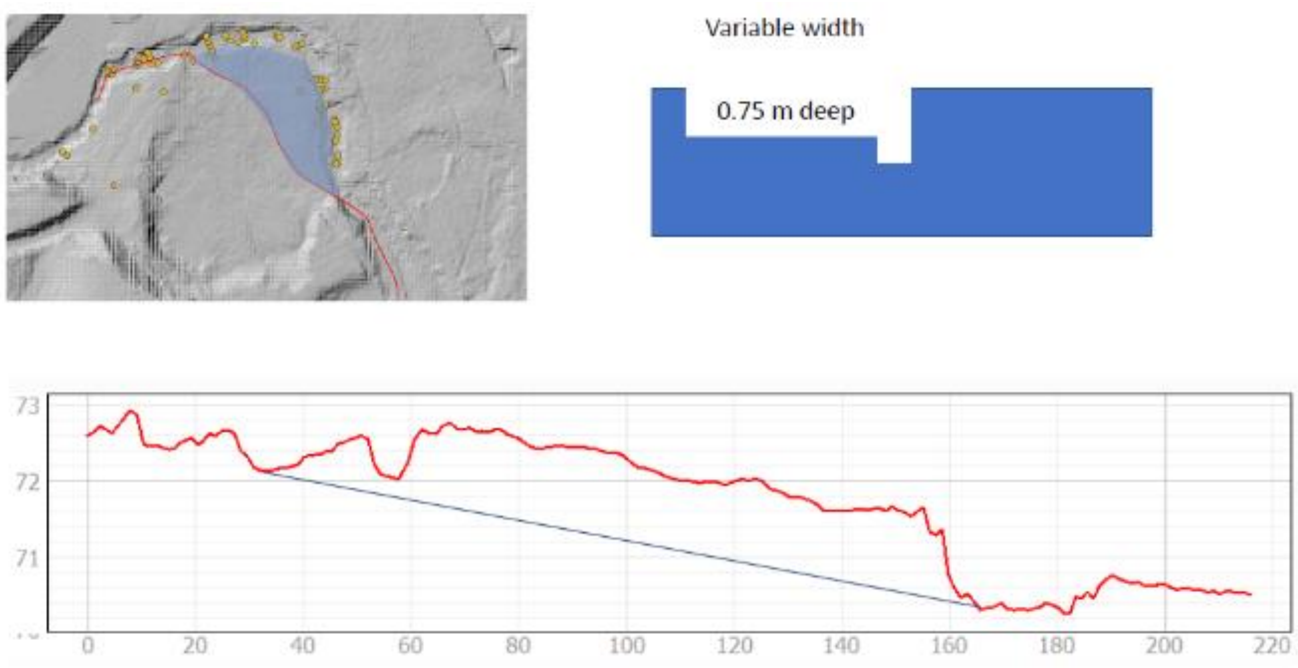


Figure 3.7. Creation of inset berm over right bank concept for Felin Puleston weir.

3.1.8 Summary

Four options were initially taken forward for further assessment using the 2D hydraulic model built for the purposes of this study to assess impacts on hydraulics in the form of bed shear stress. This provides an understanding of stability, and assesses impacts on flood risk compared to baseline. These options were considered the most viable from a stability and fish passage perspective. The four options tested and compared to baseline are:

- Option 2 - Full removal of the weir structure and bed regrading
- Option 5 - Lower weir and drown out using riffle-rapid features
- Option 6 - Bypass channel around weir over right bank
- Option 7 - Creation of inset berm over right bank

3.2 2D Flow Model Construction

To help identify and assess the potential options for the Felin Puleston weir along the Afon Clywedog, a 2D HEC-RAS model of the study reach has been developed, using available NRW 1 m cell size LIDAR and new dGPS survey. Flow information for the model was developed using an AutoRefH approach and low flows software. The model was developed at a 1 m cell size to enable accurate representation of the channel, and floodplain, that were of significant importance for the impact assessment elements of the project.

The purpose of the modelling was to appraise the preferred options identified in the sections above. This enabled assessment of the impacts to in-channel processes and the hydrological regime. The model has also assessed the impact on flood risk both locally and downstream.

The model has been built using a Digital Elevation Model (DEM) across the model domain that provides a ground elevation value for each 1 m grid cell. The model extent is shown in Figure 3.8 below.

Figure 3.8. Model extent for the Afon Clywedog study reach

3.3 Model Run Parameters

Simulated depths, velocities, water level, bed shear stress and flow were output to assess flood extents across the model domain. Monitoring lines were used at the downstream end of the model to determine likely downstream flood risk impacts. Model outputs were sensibility checked to ensure these reflected information gathered during the Fluvial Audit undertaken prior to the modelling and model results were deemed to be appropriate and sensible.

3.4 Hydrology

Flow inputs to the upstream end of the 2D model domain for the Afon Clywedog were derived from an AutoRefH approach in the absence of any gauged data. For the purposes of this assessment, a 1 in 100yr (with additions for climate change), 1 in 20yr and 1 in 2yr return period flood event have been run through the model as well as representative low flows Q95 (typical summer) and Q10 (typical winter), estimated using Low Flows 2 software. The corresponding peak flows were:

- 100yrCC – 52.2 m^3/s (40% climate change allowance)

- 20yr – 23.4 m^3/s
- 2yr – 11.0 m^3/s
- Q95 – 0.06 m^3/s
- Q10 - 1.0 m^3/s

3.5 Initial Options Bed Shear Stress Assessment

Bed shear stress model outputs show that generally under lower order floods, there would be bed shear stress values in excess of 150N/m^2 (Figure 3.9) for Options 2 and 5 (reprofiling and lowering with drowning). Most cohesive soils resist shear stresses up to 100N/m^2 so there is potential for erosion and instability as a result of these options along the impacted reach length. However, feature stability can be mitigated to a degree with the features for Option 5 (lowering with drowning) through suitable sizing of material for the rapid features. The concentration of flow within the bypass channel for Option 6 would lead to some erosion of the channel banks, with the channel likely active over the right bank flood area as a result. Bed shear stresses are reduced as a result of the proposed inset berm (Option 7) where flood energy is spread over a wider area. Bed shear stresses could exceed 200N/m^2 for Option 7 during an extreme event (Figure 3.10), demonstrating that this would still be an active zone of erosion and associated deposition during flood flows.

High shear stresses around the upstream entrance point to proposed bypassing and inset berm options could be moderated by use of a bed check feature to mitigate any potential local instability, this would be considered if any of these options are taken forward to a design phase.

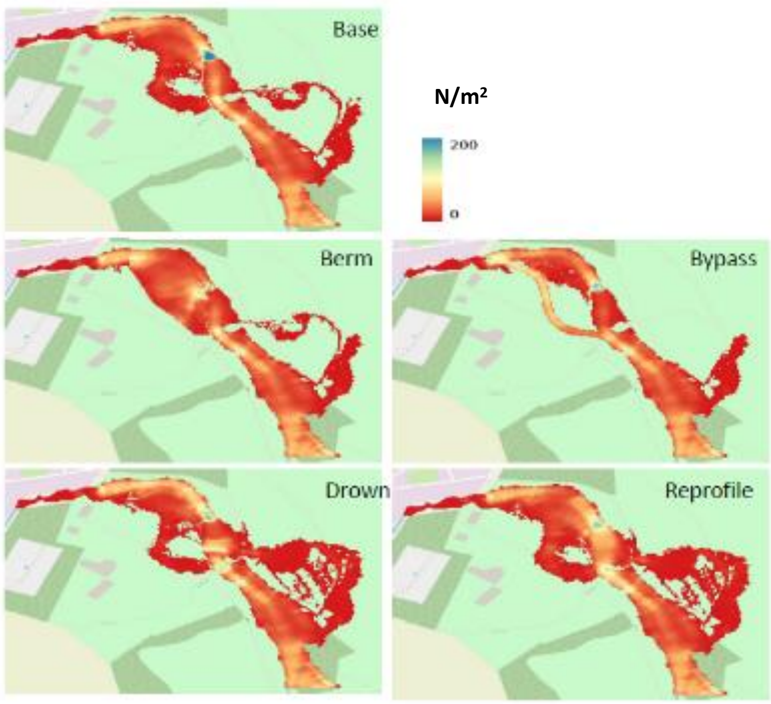


Figure 3.9. Predicted 1 in 2yr event bed shear stress (N/m^2) levels across the modelled options compared to baseline.

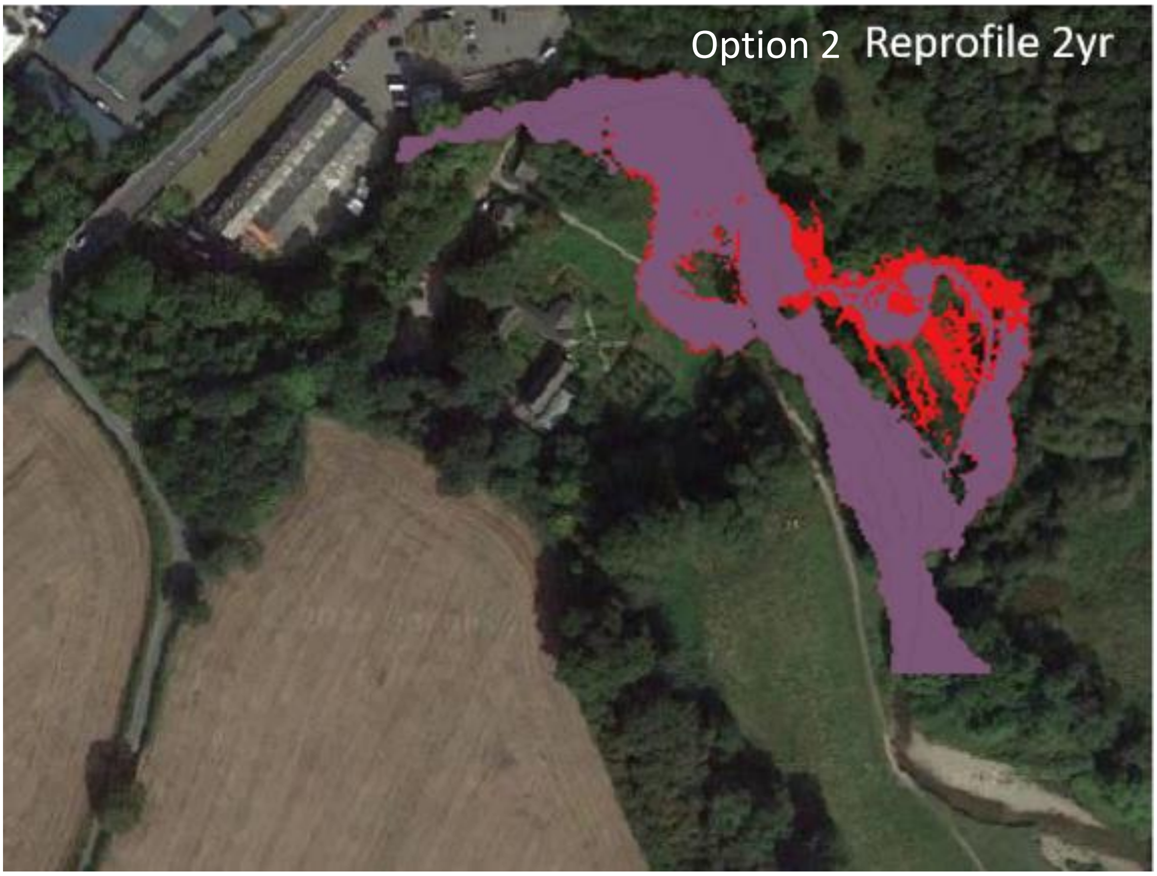
Figure 3.10. Predicted extreme event (1 in 100yr plus allowances for climate change) bed shear stress (N/m^2) levels for the inset berm and lower with drowning out options.

3.6 Initial Options Flood Risk Analysis

Initial flood modelling has been undertaken for the potential options to determine the fluvial flood risk impacts as a result of the proposed weir option compared to baseline.

Figure 3.11 shows the impact to flood extents for all modelled options (2, 5, 6 and 7), compared to baseline, for the 1 in 2yr return period flood event (baseline shown in red and option in blue – visible red shows a flood extent increase compared to baseline, visible blue and flood extent reduction and purple showing no change). For the inset berm (Option 7) and bypass channel (Option 6) options, increases in flood extent are confined to the right bank floodplain area, with small reductions elsewhere as a result. For the reprofiling (Option 2) and lower with drowning out (Option 5) options, there are increases in flood extent over the left-hand bank as a result of the introduction of the proposed features for these options that push water over the left-hand bank.

For Options 5 (lowering with drowning out) and 7 (inset berm), further return periods were run through the model following initial consultation with the client and landowner. Figures 3.12 and 3.13 show the outputs and for Option 5 (lowering and drowning out), there are small increases in flood extent compared to baseline as a result of the proposed option for the 1 in 20yr and 1 in 100yr plus allowances for climate change events. For Option 7 (inset berm), for the 1 in 20yr event, increases are generally contained within the inset berm area. There are no significant increases for the 1 in 100yr event plus allowances for climate change, with some minor reductions as a result of the storage created by the feature.


Option 2 Reprofile 2yr


Option 5 Drown 2yr

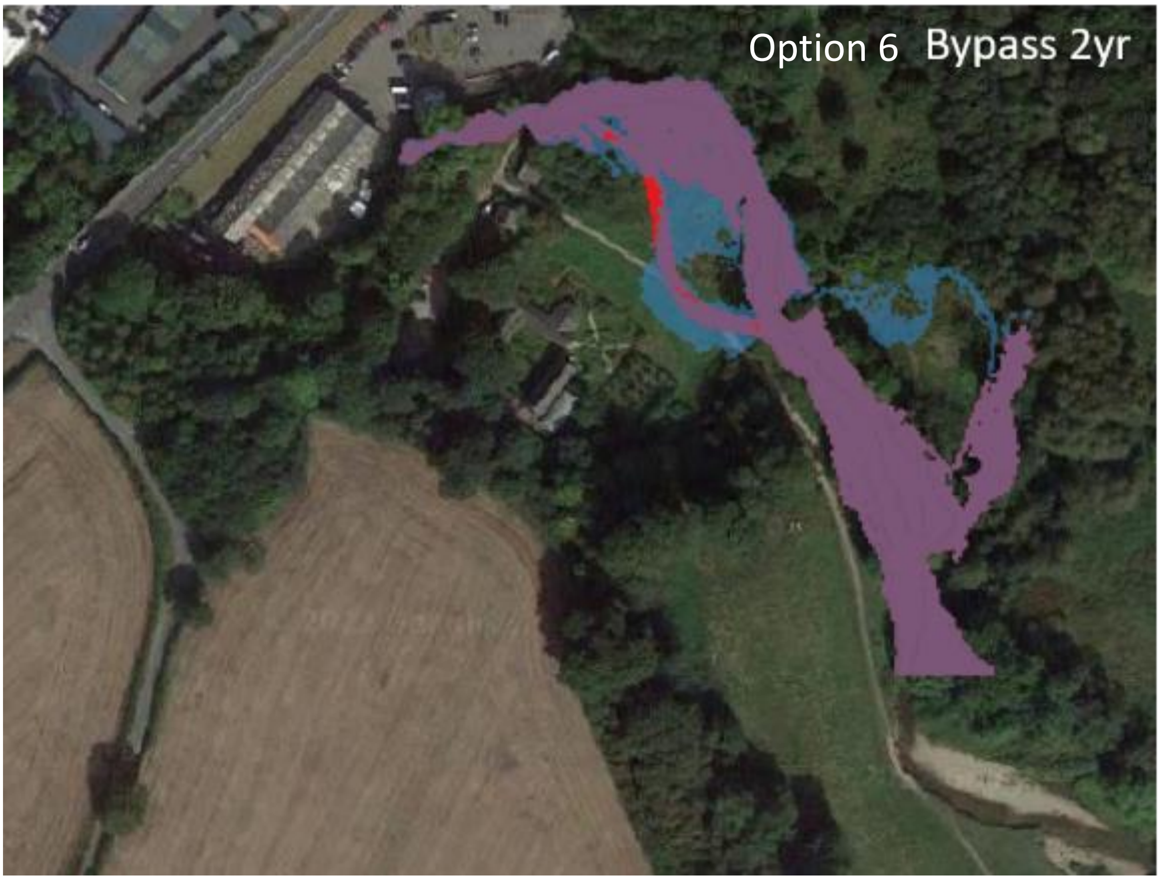


Figure 3.11. 1 in 2yr flood extent change for Option 2, 5, 6 and 7, blue = baseline, red = restored (where red is visible indicates flood extent increase compared to baseline, purple shows no change, visible blue shows flood extent reduction compared to baseline).

Figure 3.12. 1 in 20yr flood extent change for berm (Option 7) and drown out (Option 5) options, blue = baseline, red = restored (where red is visible indicates flood extent increase compared to baseline, purple shows no change, visible blue shows flood extent reduction compared to baseline).

Figure 3.13. 1 in 100yr+CC flood extent change for berm (Option 7) and drown out (Option 5) options, blue = baseline, red = restored (where red is visible indicates flood extent increase compared to baseline, purple shows no change, visible blue shows flood extent reduction compared to baseline).

3.7 Utility service searches

Figure 3.14 below shows the results of a services search for the likely impacted reach of the Afon Clywedog and surrounding area for Felin Puleston weir. Best endeavours have been used to transfer the map information to the design drawings but some error in the location of these may be present as a result. This shows there are BT Openreach and electricity lines crossing the watercourse close to the footbridge upstream of the weir. These are unlikely to be impacted by the proposed works and a bed check feature has been designed to reduce the risk of bed incision propagating upstream and impacting this infrastructure.

All services should be considered carefully by the contractor undertaking the works in terms of safe working procedures, access and crossing these utilities. It should be noted that standard services searches do not identify all local land drains. If encountered, these should be managed on site by the contractor and client. The contractor should review the services search drawing prior to construction and for potential access routes as some may be crossed to deliver the works. The client and/or contractor should undertake another services search prior to the works. The contractor should C.A.T4 / radio-detection scan, in liaison with the provider, and locate these services prior to excavation commencing if deemed required.

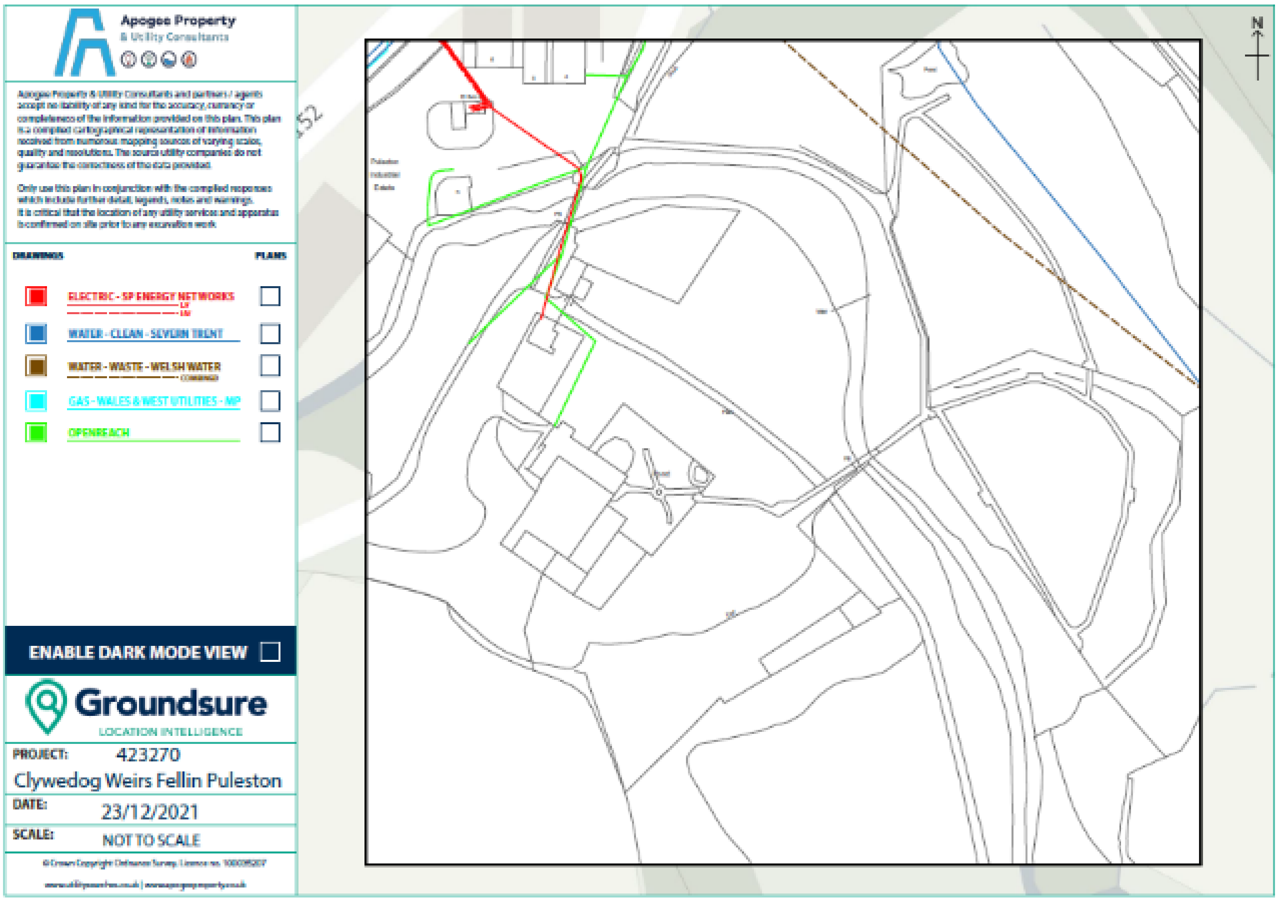


Figure 3.14. Utilities service search results for the Afon Clywedog at Felin Puleston weir study reach

Dynamic Rivers accept no liability with regards to the presence of services and whether these are encountered or impacted on site during the works. The client assumes all liability in this respect. It is strongly recommended the client and/or contractor should undertake a services search prior to the works and undertake additional C.A.T4 / radio-detection scanning before commencing works.

Contractors should be made aware of their location as it is possible that some may be crossed / passed under to undertake the proposed works. The contractor should set up goalposts in the vicinity of overhead lines so that machinery operators are aware of their presence. They should also locate any buried services before excavation begins in liaison with the service provider. Track mats may be required across buried services. Other private services, such as land drains not already mapped, that are not picked up by utilities service searches, could be encountered during the works. This should be monitored and managed by the contractor and client on site.

All services should be considered carefully by the contractor undertaking the works in terms of safe working procedures, access and crossing these utilities. It should be noted that standard services searches do not identify all local land drains. If encountered, these should be managed on site by the contractor and client.

Dynamic Rivers accept no liability of any kind for the presence or location of utilities in the vicinity of the designed features. A full and comprehensive utilities search should be undertaken prior to construction. Design drawings provided remain marked not for construction as per this recommendation.

3.8 Final Option

Following further liaison with the client and steering group, another option was developed around the principles of Option 7 that incorporated channel widening over both banks around the weir structure alongside removal of the weir and installation of rapids and bed check features. This is discussed further in Section 4 below.

4 Final design

4.1 Updated design

Following feedback from the client and other stakeholders a further revision to Option 7 was developed which would introduce inset floodplains / widening on both banks, rather than just the right-hand bank, as well as incorporation of a bed check feature and rapids.

The preferred restoration design option is shown in Figure 4.1 below following liaison with the client and iterations following discussions. Detailed design drawings have been produced alongside a Method Statement that outlines how a contractor might safely deliver the works, a Designers Risk Register that highlights all risks related to the project and a Bill of Quantities. The below sections outline the bed shear stress review that has undertaken to help with sizing of the proposed gravel features. The flood risk impacts as a result of the preferred scheme design have also been assessed.

Import of gravel/cobble/small boulder material will be required to ensure the correct mix of gravel/cobble/small boulder as per the design specification for proposed rapids and bed check features.

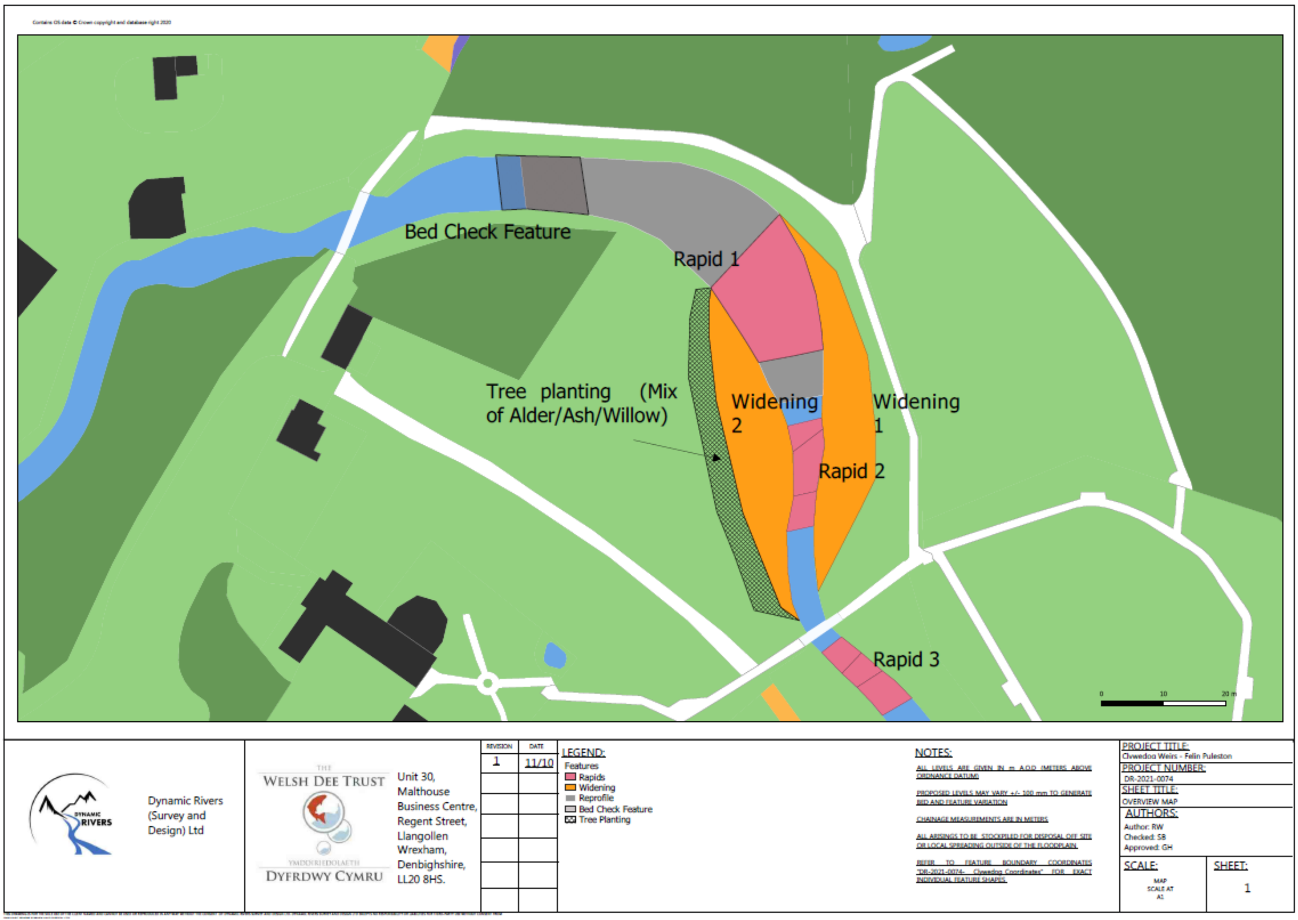


Figure 4.1. Final design for the Felin Puleston Weir removal scheme

4.2 Bed Shear Stress

Baseline bed shear stress model outputs show that generally under extreme and lower order flood flows values range between 10-600 N/m^2 (Figure 4.2 and 4.3) with the majority of these falling within the lower estimate of this range, particularly across the wetted floodplain area. Values within the channel are generally around 100-300 N/m^2 under extreme flows, with a concentration in bed shear stress over the existing weir, peaking at around 600 N/m^2. Once the weir is removed, bed shear stress in the channel generally peaks at around 300-400 N/m^2 across the introduced rapid features for extreme flows, with sizing of material for these features being guided by these figures. There are no significant changes to bed shear stress values upstream of the footbridge as a result of the influence of the rapids and bed check features for either the lower order or extreme floods modelled.

Most cohesive soils resist shear stresses up to 100N/m^2 so there is potential for erosion and instability as a result of these options along the impacted reach length. Feature stability is mitigated by the sizing of material used to create the rapids and bed check feature. Bed shear stresses are reduced as a result of the proposed channel widening where flood energy is spread over a wider area. Bed shear stresses could however still exceed 150-200N/m^2 during an extreme event (Figure 4.2), demonstrating that this would still be an active zone of erosion and associated deposition during flood flows. Lateral erosion and movement of the channel is likely. Tree planting has been recommended as part of the design to provide a medium to long term buffer for erosion towards the footpath.

Figure 4.2. Predicted extreme shear stress (N/m^2) levels across the baseline (A) and restored (B) along the River Clywedog study reach.

Figure 4.3. Predicted low order flood shear stresses (N/m^2) across the baseline (A) and restored (B) along the River Clywedog study reach.

4.3 Flood Extent Change

Flood modelling for the current and restored/weir removal site scenario has been undertaken to determine the fluvial flood risk impacts as a result of the proposed scheme. This has been undertaken for the 1 in 100 yr plus allowances for climate change, 1 in 20 yr and 1 in 2 yr events.

Figures 4.4 to 4.6 demonstrate the flood extent changes for each of the flood return periods listed above, with baseline shown in blue and the restored scenario shown in red (no change areas are shown in purple). The figures show some flood extent decreases as a result of the weir removal option for each return period modelled (visible blue areas) and small extent increases within the overall works area (mainly as a result of the widening proposed), as a result of the restored option (visible red areas). All these changes are within the overall works area. Visible purple regions indicate no change in flood extents within reasonable model and DTM tolerance and error.

Figure 4.4. 1 in 100yrCC flood extent change, blue = baseline, red = restored (where red is visible indicates flood extent increase, purple indicates no change and blue indicates reduction in flood extent).

Figure 4.5. 1 in 20yr flood extent change, blue = baseline, red = restored (where red is visible indicates flood extent increase, purple indicates no change and blue indicates reduction in flood extent).

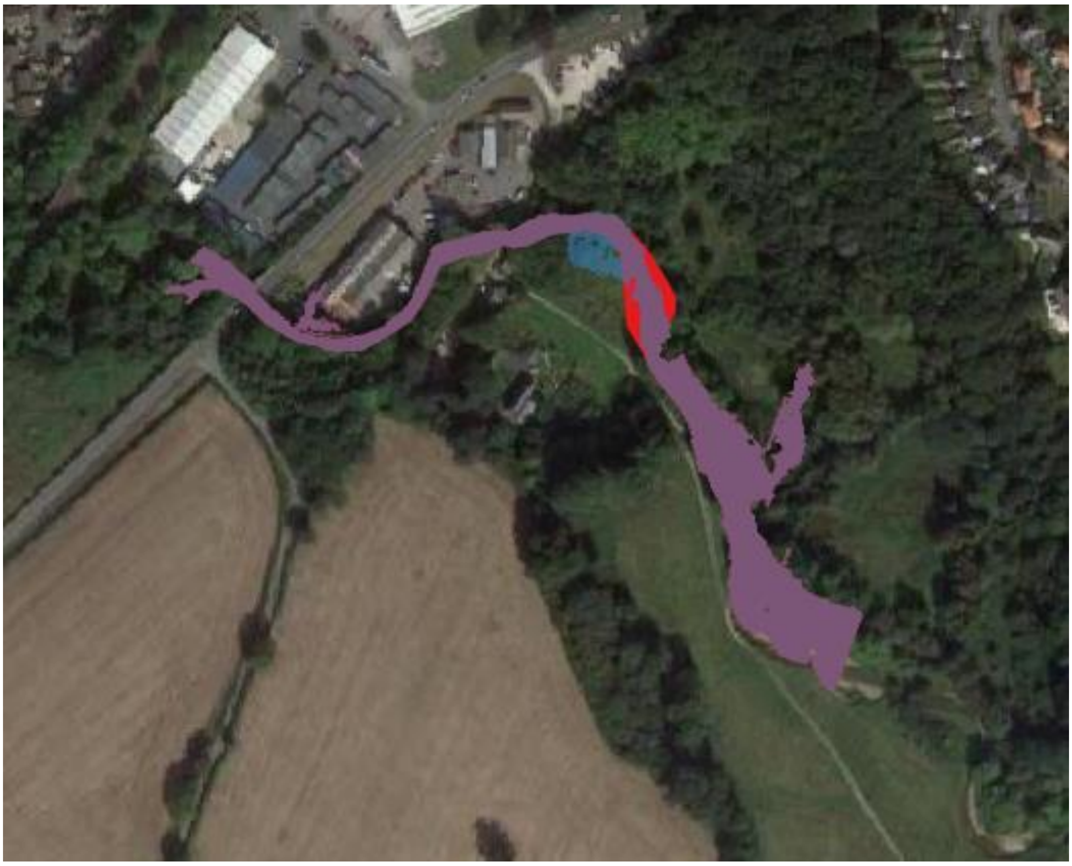


Figure 4.6. 1 in 2yr flood extent change, blue = baseline, red = restored (where red is visible indicates flood extent increase, purple indicates no change and blue indicates reduction in flood extent).

Downstream, the impact of the proposed works for all the modelled flood flows is negligible in terms of the peak hydrograph flow monitored at the downstream end of the model (Figures 4.7 to 4.9).

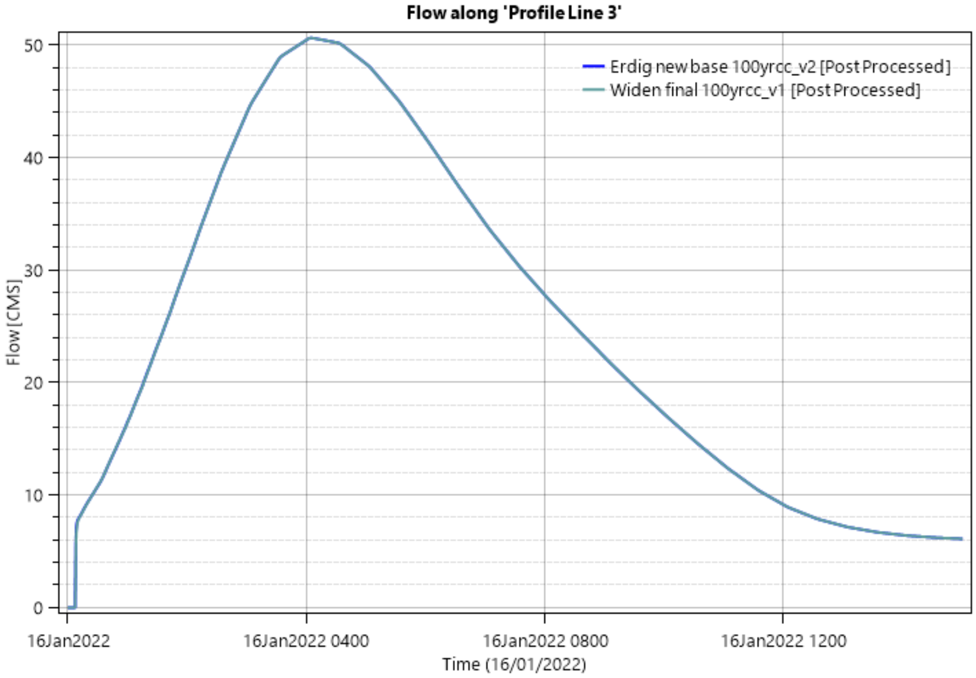


Figure 4.7. Downstream flood hydrograph change for the 1 in 100yrCC baseline and restored scenarios.

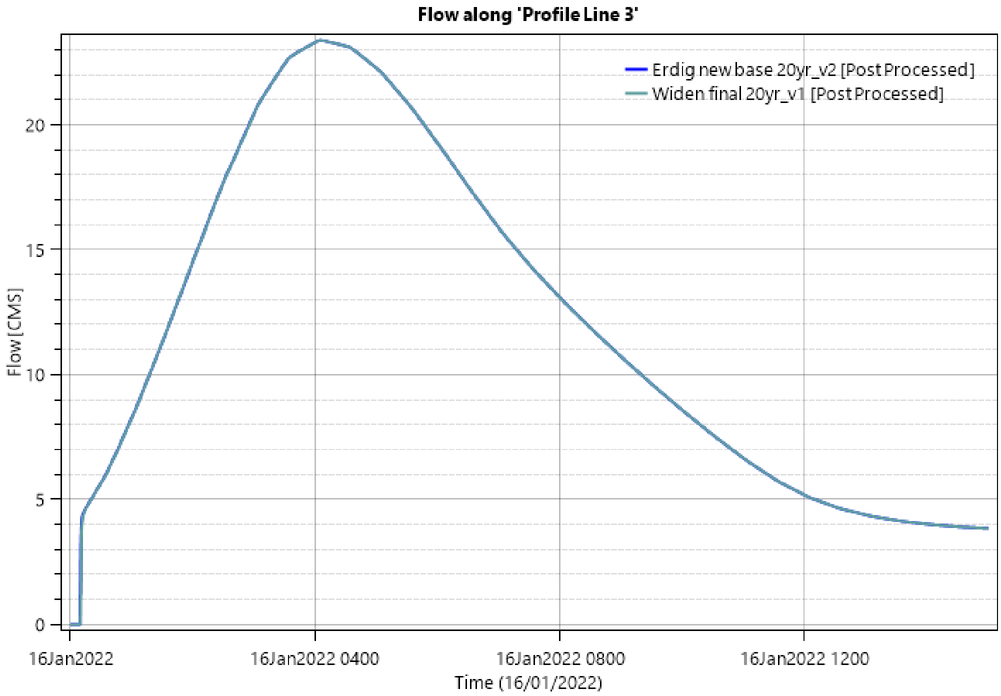


Figure 4.8. Downstream flood hydrograph change for the 1 in 20yr baseline and restored scenarios.

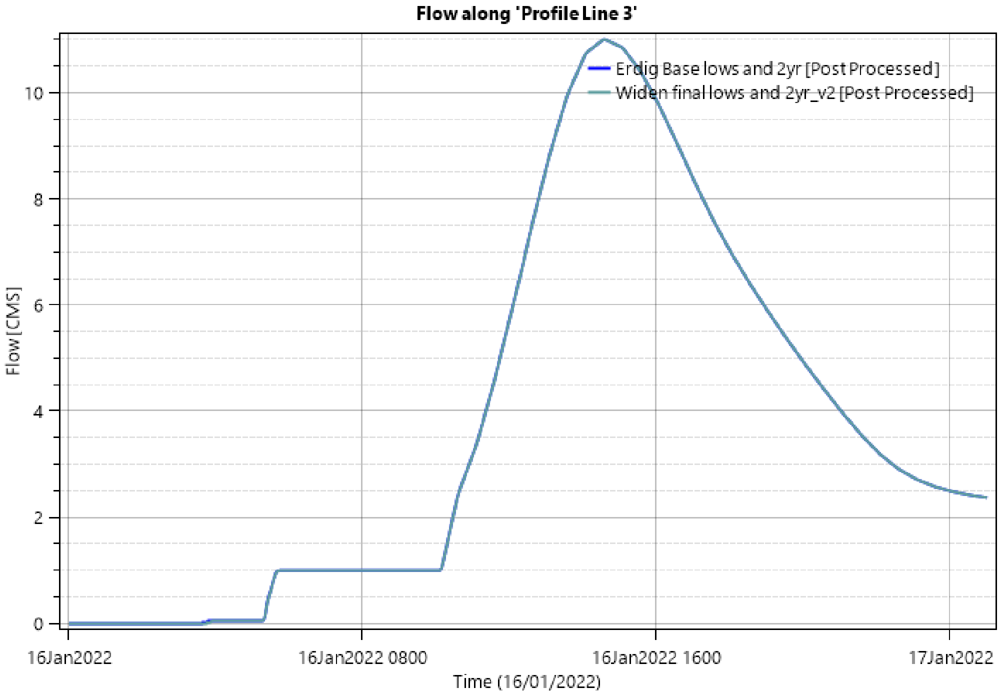


Figure 4.9. Downstream flood hydrograph change for the 1 in 2yr baseline and restored scenarios.

5 Conclusions and Recommendations

5.1 Conclusions

- The Welsh Dee Trust commissioned Dynamic Rivers to undertake the optioneering and design for providing fish passage and improving the geomorphological functioning for a weir on the Afon Clywedog to the south west of Wrexham at Felin Puleston, located on land owned by the National Trust.
- A fluvial audit and desk-based assessment revealed the Afon Clywedog is a high energy, flashy, modified river channel flowing over Holocene alluvium. There is clear evidence of historic straightening and in-channel structures are present linked to earlier industrialisation and mill operation. Surrounding hard engineering is currently failing, independent of the influence of the weir and there is ongoing erosion pressures around the weir structure itself. The steep gradient and flashy flow regime contribute to high energy conditions along the reach during flood flows that are capable of transport gravel and cobble sized material. The weir itself is a complete obstacle to fish passage and risks failure in the medium to long term which will exacerbate stability issues elsewhere.
- Four options were initially taken forward for further assessment using the 2D hydraulic model built for the purposes of this study to assess impacts on hydraulics in the form of bed shear stress. This provides an understanding of stability, and assesses impacts on flood risk compared to baseline. These options were considered the most viable from a stability and fish passage perspective. The four options tested and compared to baseline are:
    - Option 2 - Full removal of the weir structure and bed regrading
    - Option 5 - Lower weir and drown out using riffle-rapid features
    - Option 6 - Bypass channel around weir over right bank
    - Option 7 - Creation of inset berm over right bank
- Following further liaison with the client and steering group, another option was developed around the principles of Option 7 that incorporated channel widening over both banks around the weir structure alongside removal of the weir and installation of rapids and bed check features.
- Baseline bed shear stress model outputs show that generally under extreme and lower order flood flows values range between 10-600 N/m^2 with the majority of these falling within the lower estimate of this range, particularly across the wetted floodplain area. Values within the channel are generally around 100-300 N/m^2 under extreme flows, with a concentration in bed shear stress over the existing weir, peaking at around 600 N/m^2. Once the weir is removed, bed shear stress in the channel generally peaks at around 300-400 N/m^2 across the introduced rapid features for extreme flows, with sizing of material for these features being guided by these figures. There are no significant changes to bed shear stress values upstream of the footbridge as a result of the influence of the rapids and bed check features for either the lower order or extreme floods modelled.
- Most cohesive soils resist shear stresses up to 100N/m^2 so there is potential for erosion and instability as a result of these options along the impacted reach length. Feature stability is mitigated by the sizing of material used to create the rapids and bed check feature. Bed shear stresses are reduced as a result of the proposed channel widening where flood energy is spread over a wider area. Bed shear stresses could however still exceed 150-200N/m^2 during an extreme event, demonstrating that this would still be an active zone of erosion and associated deposition during flood flows. Lateral erosion and movement of the channel is likely. Tree planting has been

recommended as part of the design to provide a medium to long term buffer for erosion towards the footpath.

- The modelling has shown some flood extent decreases as a result of the weir removal option for each return period modelled (visible blue areas) and small extent increases within the overall works area (mainly as a result of the widening proposed), as a result of the restored option (visible red areas). All these changes are within the overall works area. Visible purple regions indicate no change in flood extents within reasonable model and DTM tolerance and error.

5.2 Recommendations

- It is critical that the hydraulic regime across the site is in line with the newly created features to ensure the site will function, it is recommended that Dynamic Rivers supervises the site works during construction, as detailed in the accompanying Method Statement.

- Best endeavours have been used to transfer the map information to the design drawings but some error in the location of these may be present as a result. This shows there are BT Openreach and electricity lines crossing the watercourse close to the footbridge upstream of the weir. These are unlikely to be impacted by the proposed works and a bed check feature has been designed to reduce the risk of bed incision propagating upstream and impacting this infrastructure. All services should be considered carefully by the contractor undertaking the works in terms of safe working procedures, access and crossing these utilities. It should be noted that standard services searches do not identify all local land drains. If encountered, these should be managed on site by the contractor and client. The contractor should review the services search drawing prior to construction and for potential access routes as some may be crossed to deliver the works. The client and/or contractor should undertake another services search prior to the works. The contractor should C.A.T4 / radio-detection scan, in liaison with the provider, and locate these services prior to excavation commencing if deemed required.

- Dynamic Rivers accept no liability of any kind for the presence or location of utilities in the vicinity of the designed features. A full and comprehensive utilities search should be undertaken prior to construction. Design drawings provided remain marked not for construction as per this recommendation.