# Vyrnwy Audit, Optioneering and Design

# FINAL Report

## Canal & River Trust

## Quality information

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# 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

Canal & River Trust (herein referred to as the client) commissioned Dynamic Rivers to undertake river and floodplain restoration along River Vyrnwy using process-based principles that will allow the river and valley bottom to develop and function more naturally (Figure 1.1). The site comprises an elevated floodplain on the right bank of the River Vyrnwy and an area of improved grassland for grazing. The client plan to purchase the land and grazing can potentially be removed to allow natural floodplain vegetation to recover and associated wetland habitat to develop providing wet conditions allow (Figure 1.1).

**Figure 1.1. Restoration area on the River Vyrnwy Floodplain. (Copyright Google Earth 2024.)**

## 1.2 Approach

We have gained a detailed understanding of the state, activity and sensitivity of the study watercourses through the study reach, through the review of archival maps and aerial photography illustrating system functioning over both historical and recent time. This was combined with a walkover that helped confirm the landscape features identified during the desk study, identifying sediment sources and sinks, geomorphological units and identifying geomorphological processes linked to the sediment transport and the likely channel change regime. All data were reviewed against the 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 verify options from a geomorphological process perspective.

We have quantified the geomorphological and flood risk impacts of the preferred option, using a 2D hydraulic model (HEC-RAS) for the river, utilising Natural Resources Wales (NRW) LiDAR data and survey from NRW model data (flow information was obtained using a gauged value and AutoRefH approach). The 2D modelling approach has been applied across both the river and 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 to ensure they are appropriate for a naturally functioning watercourse of this type. The model was also used to determine impacts on the flood hydrograph downstream by monitoring the flow at the downstream end of the model and comparing it to the baseline outputs.

# 2 Data Review and Fluvial Audit

## 2.1 Desk Study and Field Audit – System Functioning

The River Vyrnwy is generally an active single thread, gravel/cobble river with a moderate gradient, with evidence of extensive floodplain reworking preserved in the landscape (Figure 2.1). It has been modified in the past and displays evidence of channel straightening to the west of the study site (Figure 2.2). Activity levels at the study site appear reduced with little change to the planform of the river between the 1880 Ordnance Survey map and present (Figure 2.3). However, there are sinuous reaches in the locality of the study reach and where the channel becomes generally more laterally active with clear evidence of channel bar growth and riffle/rapid presence (Figure 2.4). The development of the sinuous reach within the study area is further demonstrated in historic Google Earth imagery (Figure 2.5) and demonstrates that increased deposition in the channel will result in local erosion and impacts to in-channel processes.

These features were observed on site, with active bar gravels evident as a result of the developing features (Figure 2.6). Bank erosion occurring in response to development of these features was also noted on site (Figure 2.7).

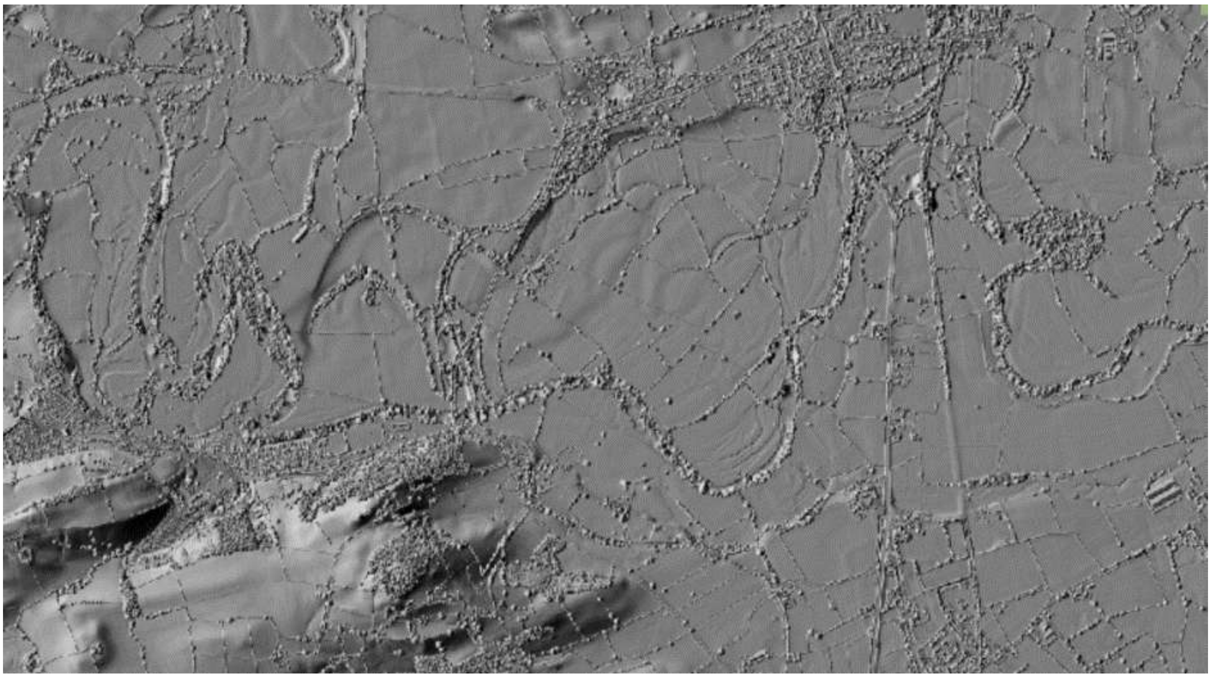

**Figure 2.1. LiDAR of the wider River Vyrnwy landscape.**


**Figure 2.2. Historically straightened reach of the River Vyrnwy (Copyright Google Earth 2024).**

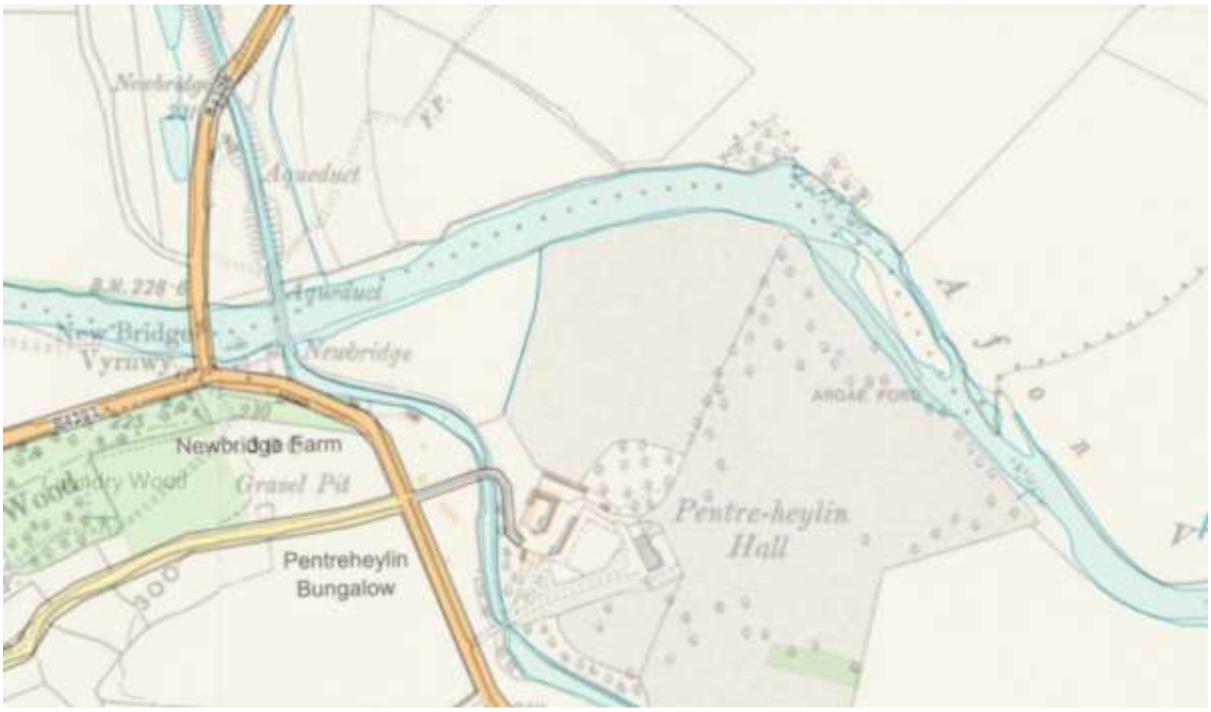


**Figure 2.3. River Vyrnwy contemporary and historic (1880) planform.**



**Figure 2.4. Dynamic sinuous reaches of River Vyrnwy; TOP – study reach, BOTTOM – further downstream. Copyright Google Earth 2024.**

**Figure 2.5. River Vyrnwy contemporary barform dynamics (Copyright Google Earth 2024).**

**Figure 2.6. Active bar gravels on the River Vyrnwy along the study reach.**

**Figure 2.7. Right bank erosion on the River Vyrnwy along the study reach.**

Inspection of the LiDAR data for the study reach and associated floodplain suggests that the main river is well connected to its floodplain at the study site (Figure 2.8) with a width/depth ratio of 40, however river depth is likely to be underestimated in these data as the LIDAR data appears to provide a poor representation of the channel depth (this was found to be the case as a result of the supplied NRW model for the study reach).

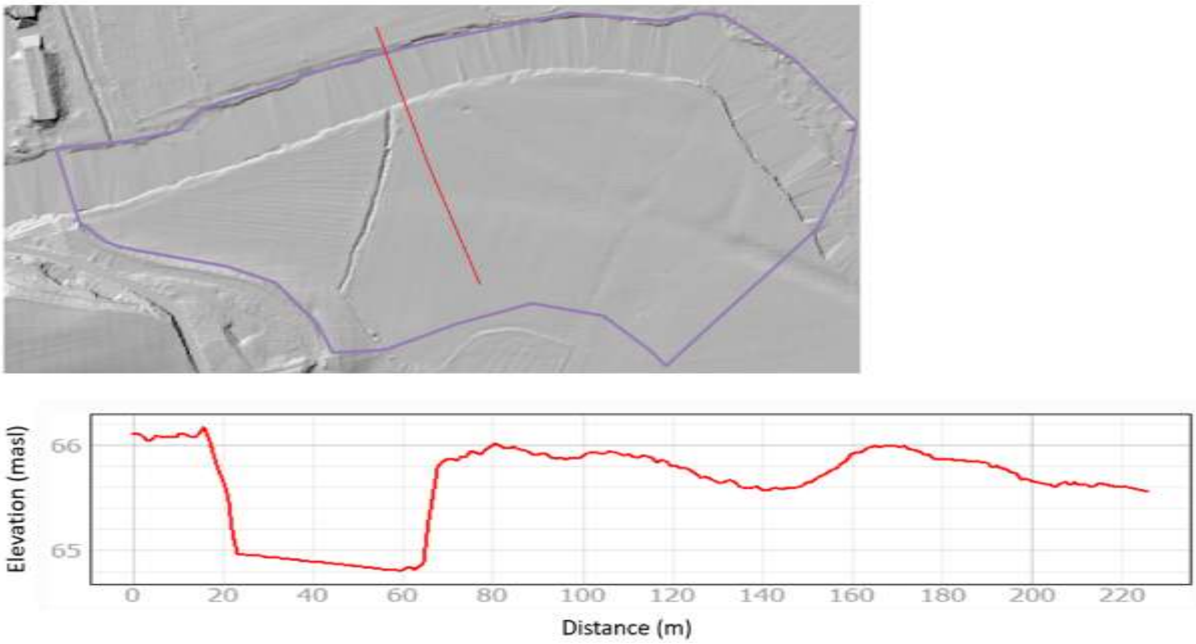


**Figure 2.8. Cross-section through the River Vyrnwy.**

Figure 2.9 illustrates the spatial variation in connectivity with a clear central band of better-connected floodplain that could act as a seasonal channel or backwater route and this is supported through preliminary rainfall modelling (Figure 2.10) that also identifies this line as a lower area on the floodplain. The rainfall accumulation pattern also suggests several other areas which would be appropriate for open water and/or wetland creation.

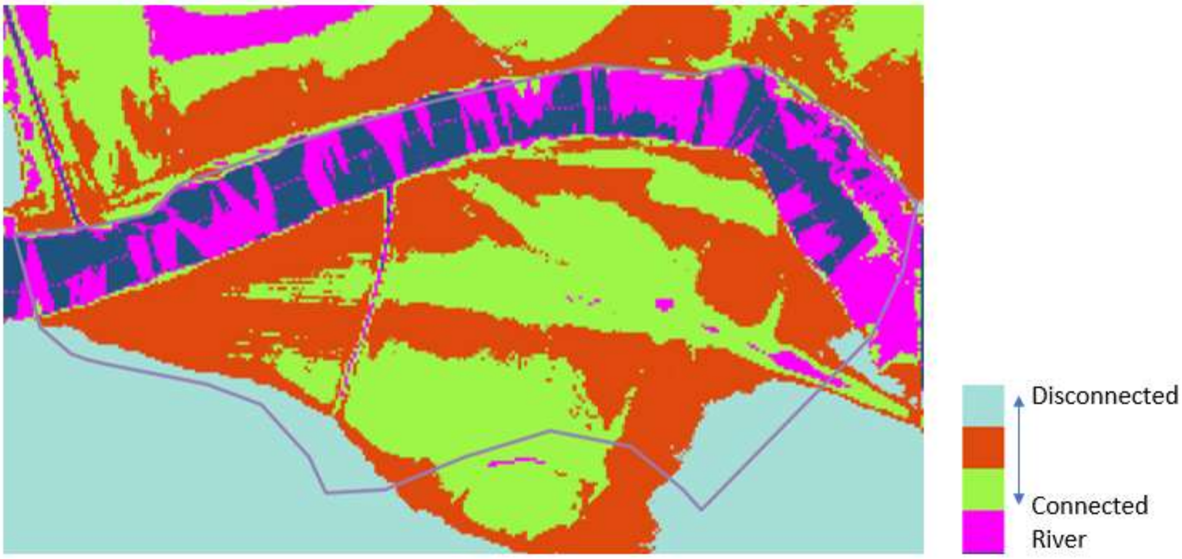


**Figure 2.9. Spatial connectivity variation across the study site on the River Vyrnwy.**

**Figure 2.10. Rainfall accumulation zones across the study site on the River Vyrnwy.**

A long section through the possible new channel or backwater line (Figure 2.11) suggests that it will be a low gradient secondary flow route and may be prone to medium to long term deposition of gravels, however, this is not considered to the unnatural for a watercourse of this type.

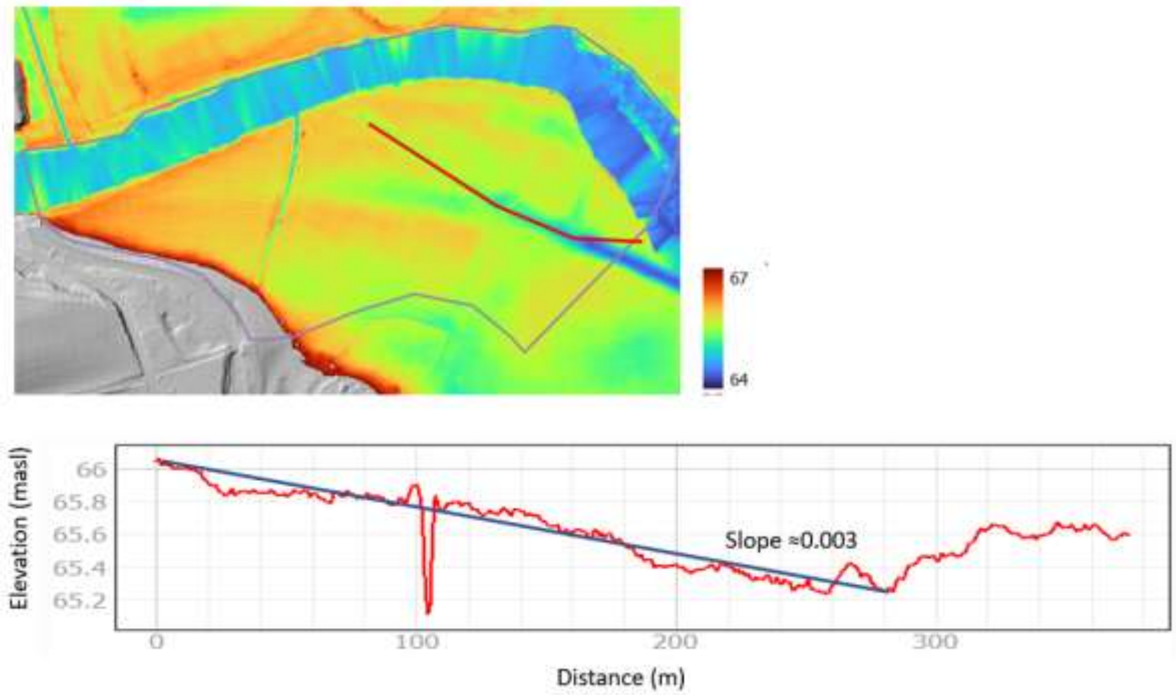


**Figure 2.11. Long section through the floodplain of the River Vyrnwy.**

The site visit and fluvial audit confirmed that the river channel bed along the study site is significantly lower (Figure 2.12) than that represented in the LIDAR that provides a constraint on the likely frequency of wetting into any features considered for the target floodplain area, as described in the optioneering section below.

**Figure 2.12. Image showing depth of channel compared to floodplain.**

The floodplain area within the study area is generally improved grassland that has been grazed (Figure 2.13). There are evident palaeo channels that are wetter at least during the winter months due to them being a topographic low within the floodplain area (Figure 2.14). Wrack lines in the hedge around the property to the south suggests significant recent out of bank flooding during the winter months.

**Figure 2.13. General floodplain condition in the target restoration area.**

**Figure 2.14. Palaeo channel just to the north of the study area holding water following winter rainfall (TOP) and drier palaeo through the study area itself (BOTTOM).**

There is a ditch draining from south to north into the Vyrnwy that is capturing flow from a sluice structure linked to the canal to the south of the site area (Figure 2.15). It is understood from the Canal & River Trust that the current constant flow coming from this sluice structure is a result of a failure of the structure and current bypassing of flow around it and into the ditch (Figure 2.16), as witnessed on site. This ditch has been targeted for works on the assumption that flow will continue into this ditch into the future as this will help to wet a wider area of floodplain and create more wetted area that is an overall target of the restoration scheme for the Trust. It is also assumed that the ditch will receive minor baseflow from the surrounding superficial geology following rainfall events.

**Figure 2.15. Target ditch general character as it approaches the Vyrnwy.**

**Figure 2.16. Flow bypassing the sluice structure from canal into the target ditch.**

In summary, it would appear that there are opportunities to restore the river and floodplain in the target area along the River Vyrnwy. A constantly flowing channel through the study site is unlikely feasible due to the significant height discrepancy between the existing channel bed and floodplain (subsequently confirmed by received NRW model). However, other options are available, including targeting of the ditch flow, as described in the optioneering section below. It is likely that gravel deposition will be enhanced in the main channel and across the floodplain, enhancing system variety and dynamism in the process.

# 3 Optioneering and Modelling

## 3.1 Optioneering

A number of reconnection options were considered at the site to the connectivity between the River Vyrnwy and the floodplain. Optioneering considered backwater creation to enhance seasonal wetness by exploiting the already lower areas of the site and blocking the ditch to the west of the site.

Initial optioneering efforts were aimed at maximising potential suitable habitat for Luronium natans to compensate for Montgomery Canal works being undertaken by the Client, works are aiming to establish suitable habitat within offline reserves. Habitat requirements for Luronium initially considered two states of the plant which exists as one form in deeper water and another towards marginal muddy areas.

Habitat requirement initially targeted creating open water ponded depth to a depth of 2m within restoration features, this was taken as a guide for suitable habitat for Luronium natans from Natural England literature reviewed by Dynamic Rivers. Site constraints and principally the significantly elevated floodplain above the channel showed that achieving this ponded depth at summer flows was not possible. Discussion between Dynamic Rivers, NRW and the client ecology teams suggested that the habitat target could be relaxed to 1m ponded depth of open water during summer. This assumption is based on examples in France where the plant has thrived in ditch environments with much shallower depths. Subsequently, it was advised by the client ecologist that the species could survive in much shallower water for a significant duration of time, should the 1m depth not be achievable during summer and the target was relaxed to 1m depth during winter flow following agreement with the client. Alongside the aim of habitat creation, the client and NRW are ambitions to produce as close to a naturally functioning river restoration as possible.

Options 1 and 2 were initial river restoration focused ideas, targeting historic features on site, these options did not provide enough ponded water and it was agreed to assess Option 3 which was less naturalised but may provide the habitat required. Option 3 was then discounted during stakeholder discussion due to being similar to other offline reserves within the catchment which had proved a maintenance burden for the client, without offering any wider naturalisation benefit. Option 4 a and b considered exploiting the historic paleochannel features to create localised over excavated habitat and reconnect a historic river feature, however the option did not provide enough habitat to be viable. Option 5 is an extended and over-excavated development on option 4, whilst targeting the paleochannel locations to re-use historic river feature, it also creates a large inset area consisting of gravel island, bar and multi thread chute-backwater channels to provide a diverse habitat template, the large cut means during winter flow a larger ponded area will exist.

Options considered include:

- Option 1 – backwater creation and palaeo channel excavation. Initial naturalised option with deep sections of open water to provide habitat for *L. natans.*
- Option 2 – extension of Option 1 to increase deepness of features, with extra chute channel from the Vyrnwy. Aims to target summer connectivity.
- Option 3 – large pond style excavation connected via backwater channel. Option not naturalised but aimed at maximising habitat potential for *L. natans.*
- Option 4a – Southern palaeo channel backwater excavation aimed at targeting natural function whilst maximising habitat for *L. natans.*
- Option 4b – Amendments to 4a to change slopes and depths, less naturalised morphology but deeper ponded flow for habitat.

- Option 5 – Large backwater excavation with chute channels, bars and sinuosity. Inset from floodplain but analogous to elsewhere on the Vyrnwy, particularly bar backwater development downstream from the site.

### 3.1.1 Character and Impacts

The audit and modelling work undertaken to inform the optioneering resulted in the identification of the following significant constraints and opportunities:

- Significant channel and floodplain disconnection restricting vegetation community development;
- Significant channel and floodplain disconnection preventing the Vyrnwy and floodplain from connecting in all but flood flow;
- Existing palaeo channels and lower sections of the site offer opportunity to increase floodplain connectivity with reduced excavation compared with elsewhere on site;
- The ditch to the west of the site with minor baseflow offers an opportunity to increase surface wetness (also currently supplemented by flow from the canal).

## 3.2 Option 1

The initial option comprised two moderately sized backwater features, with varied excavation elevations to help develop ponded flow of differing depths and develop diverse wetland habitat. Greater than 1m deep open water sections towards the centre of the features were intended to provide habitat for L. natans, similar deep open water excavations were proposed along a palaeo channel feature to the south of the site. Chute channels from the western ditch were included to push additional flow into the floodplain and features.

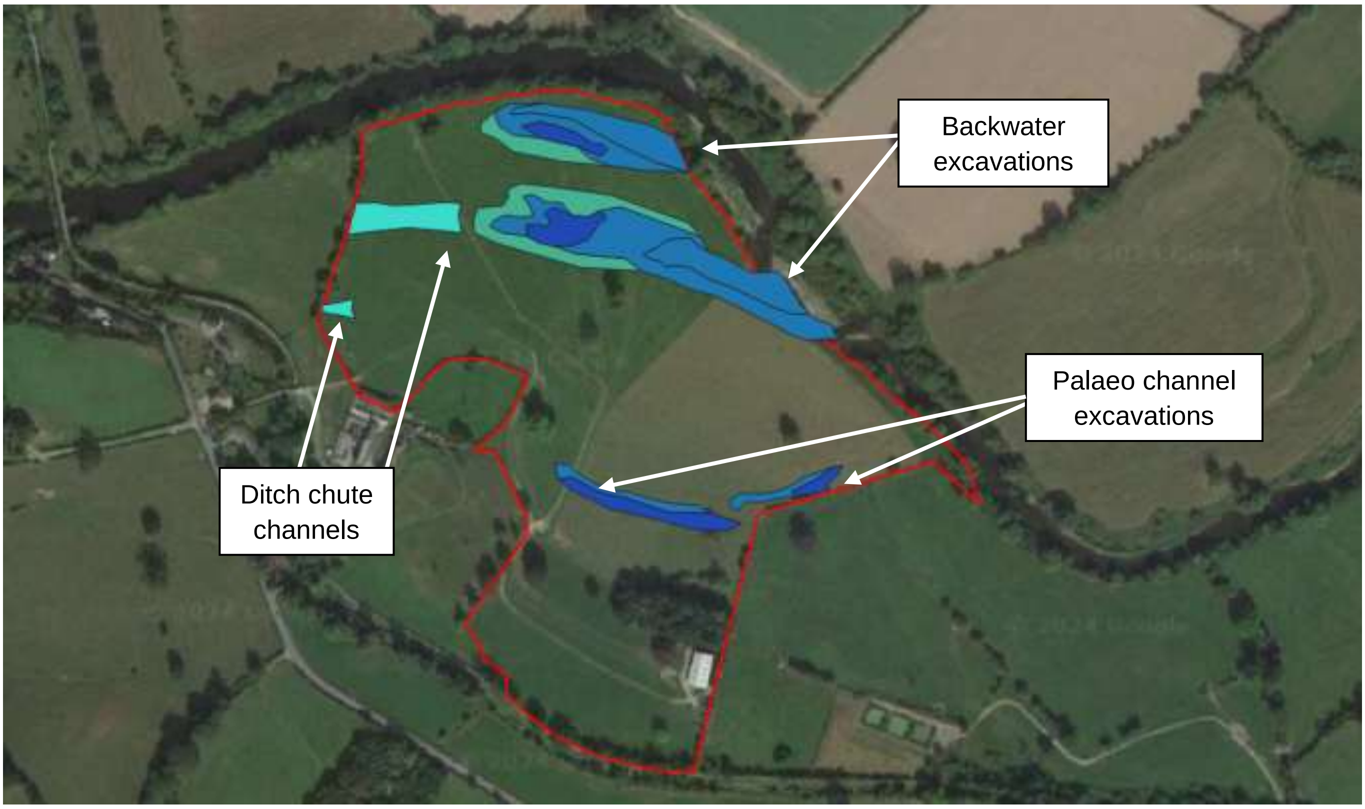


**Figure 3.1. Option 1 backwater and palaeo channel excavations**

### **3.2.1** Impacts and recommendations

- Option was discounted following initial analysis showing habitat suitability was poor, not pursued in favour of deepening excavations.

**Recommendation: Do not pursue**

## 3.3 Option 2

The Option 1 backwater arrangement was further developed and extended to provide an opportunity to maximise connectivity to the Vyrnwy at summer flows, opportunities for material disposal were also considered and the option is shown in Figure 3.2. A chute channel from the Vyrnwy was added and ditch infilling downstream from both ditch chutes was added to encourage flow to spill into the floodplain.

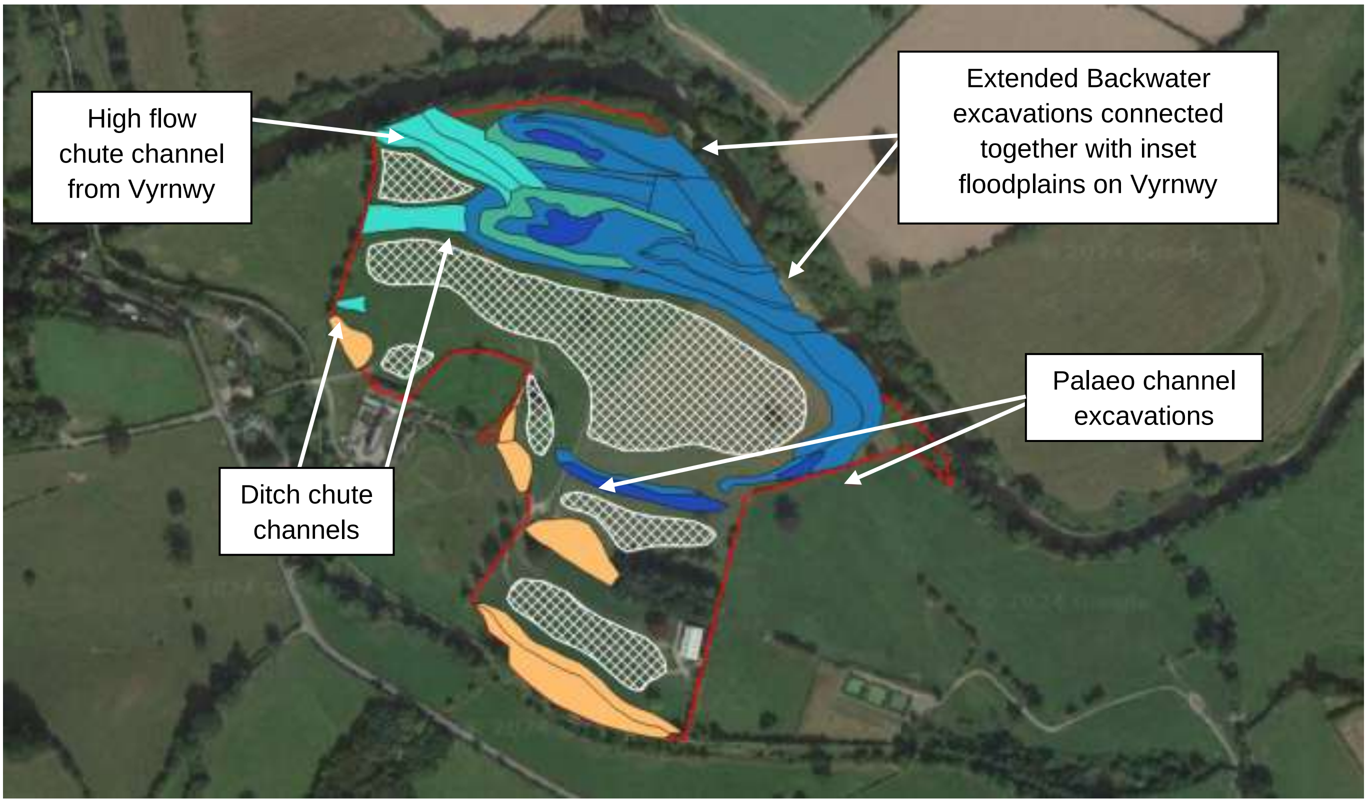


**Figure 3.2. Option 2 backwater and palaeo channel excavations extended. Hatching is opportunity for low-height material spreading with orange representing river terrace extensions to re-use arisings.**

### 3.3.1 Impacts and recommendations

- Option was discounted due to volume of cut required and not providing ideal habitat target for *L. natans.*

**Recommendation: Do not pursue**

## 3.4 Option 3

During presentation of the Option 2 connected backwater arrangement, it was discussed that the chute from the Vyrnwy caused winter flow velocity to exceed 1m/s, this is not ideal for *L. natans* and excavation volumes were significant whilst still not providing significant amounts of suitable habitat. It was agreed with the Client to test a 'less naturalised' option but with the view of solely maximising available open water habitat. Therefore, a large pond connected to the Vyrnwy with a backwater feature was tested. Ditch blocking, chutes and southern palaeo channel excavation were all retained. The option is shown in Figure 3.3 below.

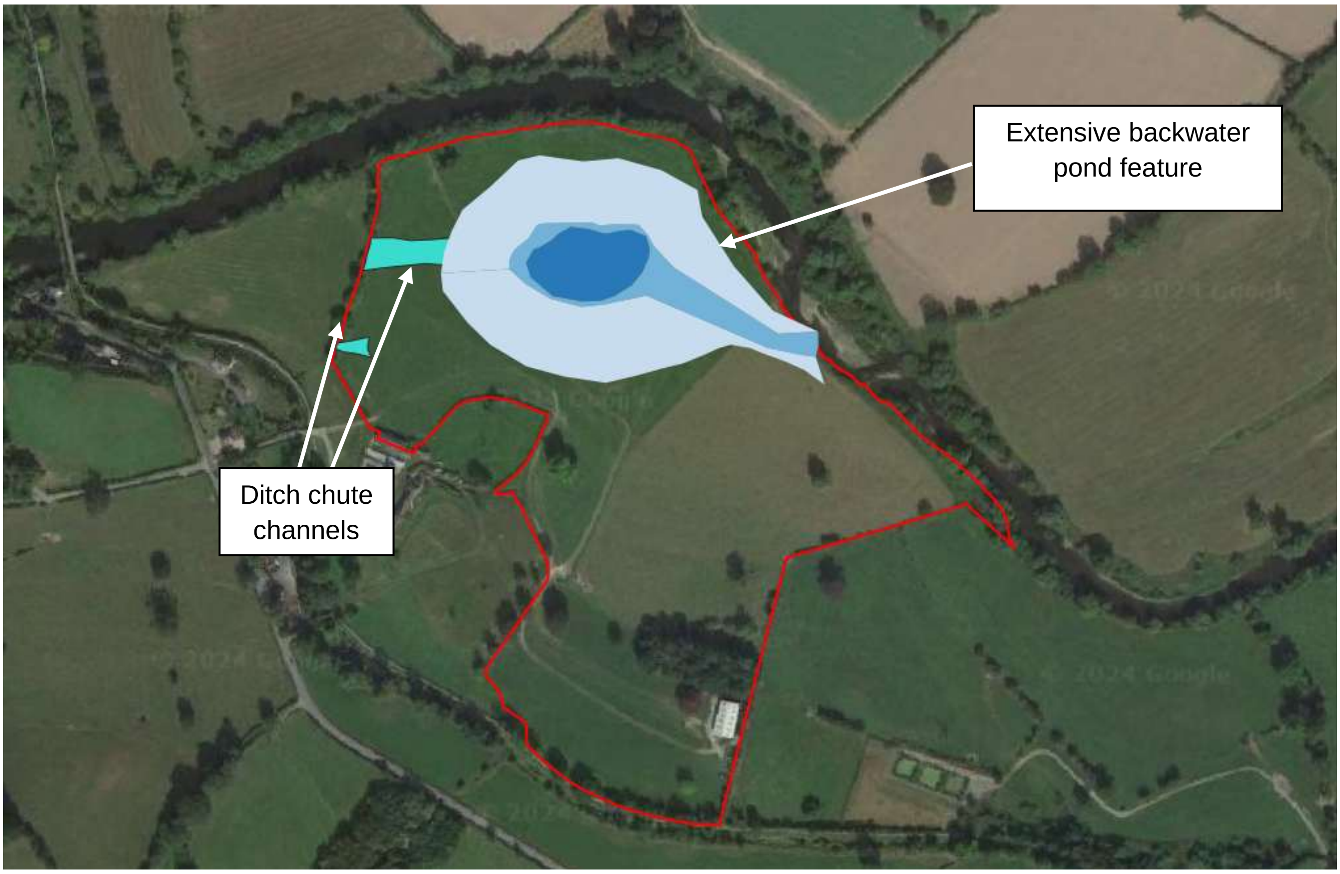


**Figure 3.3. Option 3 overlarge backwater pond feature.**

### **3.4.1** Impacts and recommendations

- Option was discounted due to volume of cut being significant and not providing ideal habitat target for *L. natans.*
- Additionally, the project team comprising client and Dynamic Rivers agreed this option does not provide a naturalised opportunity for a river restoration at the site and it was agreed to focus on prioritising restoration rather than being guided solely by appropriate *L. natans* habitat creation.

### **3.4.2** Option 4a

Following presentation of Option 3, which resulted in a significant amount of potential excavation and still not providing 4ha of 1m depth open water, it was agreed that the excavation depth required to achieve 4ha surface area of 1m depth open-water is likely unachievable. This is caused by the significant disconnection of the Vyrnwy to the majority of the site during summer and normal winter flow, as such an infeasible amount of arising volume would be generated to connect these flows and achieve 1m flow depth. It was agreed to re-investigate palaeo channel excavation, but focus on one location and over-excavate the feature to provide a naturalised backwater feature that also provides some habitat for *L. natans*. This option is presented in Figure 3.4 below.

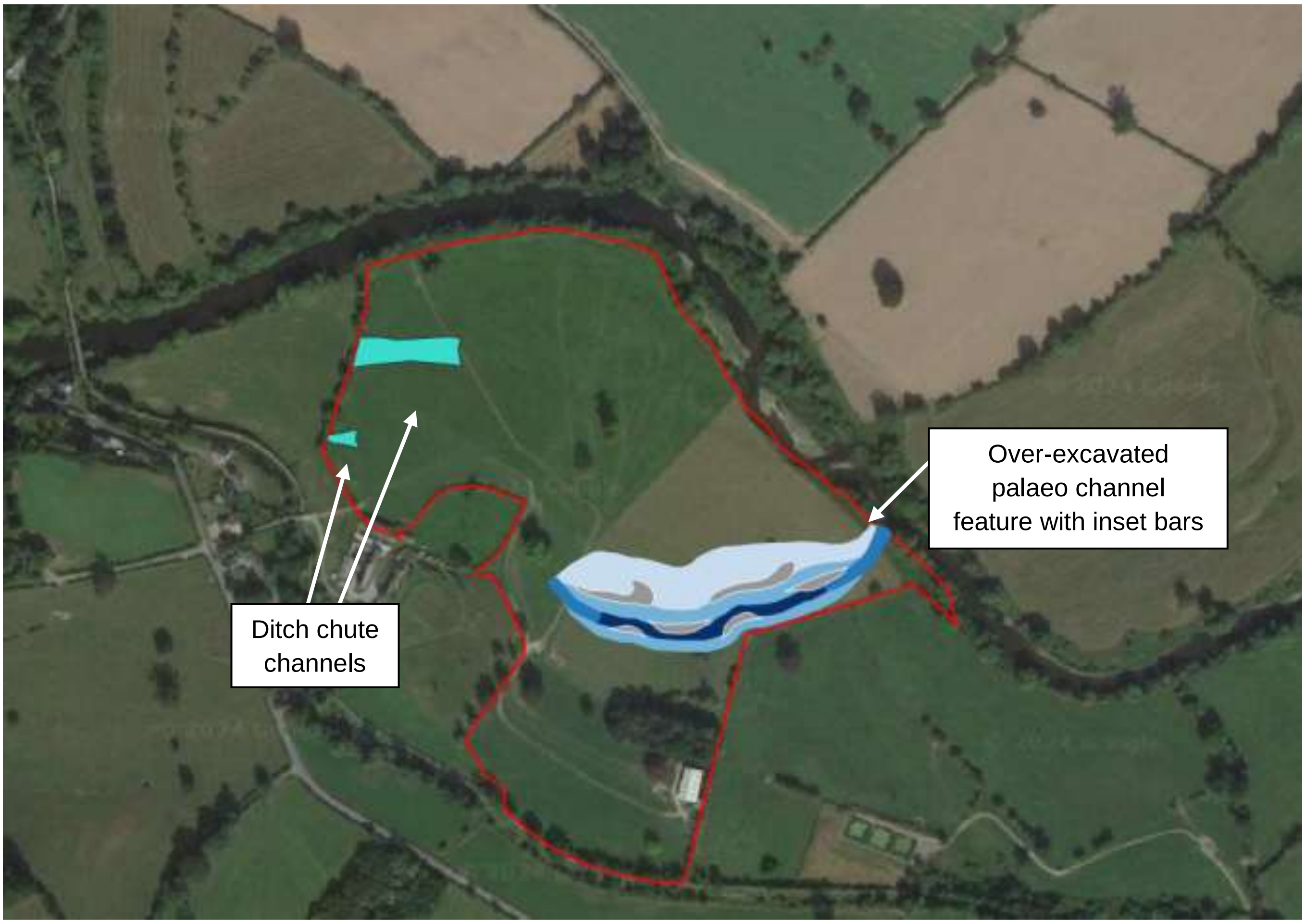


**Figure 3.4. Option 4a over excavated palaeo channel with berms and bars providing a naturalised option whilst also providing *L. natans* habitat. Different blue colours indicate different average depth of bench/slope features and grey features represent bar features.**

### **3.4.3** Impacts and recommendations

- Option was reviewed internally within Dynamic Rivers and agreed to discuss with the client team for possible progression.
- It was also agreed to test a modified morphology version of the option with differences to benches/slope in the feature (Option 4b) to try and increase habitat for *L. natans* whilst reducing potential arisings.
- Option ultimately discounted in favour of Option 5 due to overall gains.

**Recommendation: Do not pursue**

### 3.5 Option 4b

This option is a modified version of the over-excavated palaeo channel (Option 4a) which aims to provide more habitat availability for *L. natans* within a similar footprint, the option also reduced the potential volume of excavated material and is demonstrated in Figure 3.5.

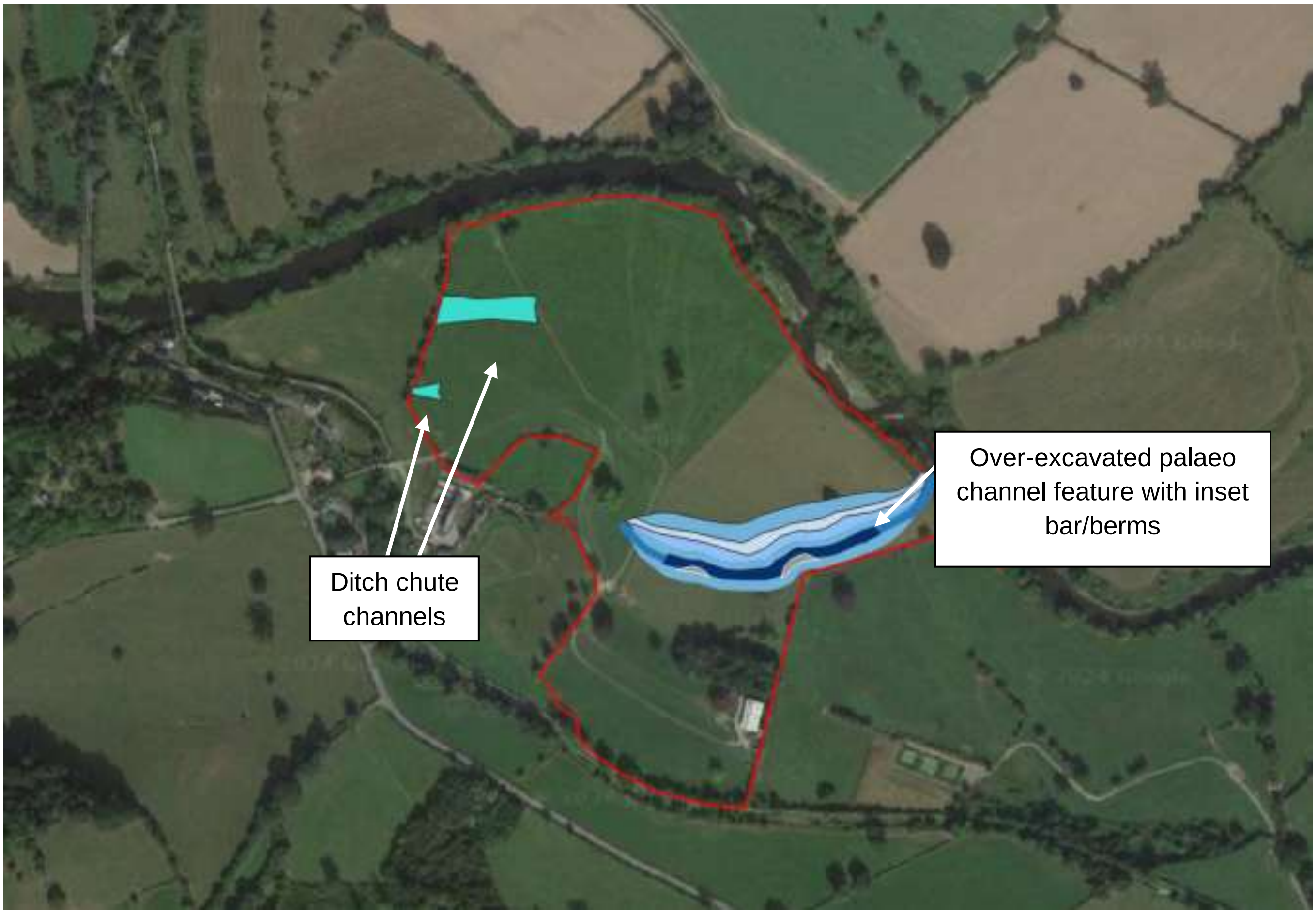


**Figure 3.5. Option 4b second iteration of single over-excavated palaeo channel feature, intention to increase habitat and reduce cut versus Option 4a. More uniform benches than Option 4a at different elevations represented by different shades of blue colouring.**

#### 3.5.1 Impacts and recommendations

- Option was presented to client but agreed it still produced a significant amount of excavation for limited habitat benefit.
- It was agreed with the client team for Dynamic Rivers to undertake a final option variation targeted on a naturalisation driven approach to the backwater creation, with the *L. natans* habitat availability not being a principal direction guiding in the option (see subsequent Option 5).
- Additionally, the project team comprising client and Dynamic Rivers agreed that Option 4a and 4b do not provide the best opportunity for a naturalised option at the site and it was agreed to further focus on prioritising restoration rather than being guided solely by creation by *L. natans* habitat.
- Option ultimately discounted in favour of Option 5.

**Recommendation: Do not pursue**

### 3.6 Option 5

Following presentation of the Option 4 over-excavated paleochannel options, it was agreed to test an option which works better with natural processes for the site rather than being solely driven by creation of *L. natans* habitat. Option 5 has been developed utilising analogue information from the dynamic reach of the Vyrnwy downstream from the site which includes a bar/backwater section (Figure 3.6). This option comprises two backwater features, with the southern feature having two backwater branches. Within the backwater excavation channels there are bar features with chute channels, and a vegetated island within the southern feature. Option 5 provides a significant improvement in diversity of features and habitat types compared to other options considered, which will provide various wet and semi-wet locations. This will continue to evolve post-construction following sequences of erosion and deposition as well as vegetation establishment across the features.

The ditch blocking and associated chutes are retained to provide a potential source of floodplain wetting and the kested hedge is proposed to provide a benefit to terrestrial ecology whilst utilising a small amount of arisings for construction. The raised ground associated with the kested hedge holds some flow on the Vyrnwy site during flood flows and prevents this from passing downstream onto adjacent land, however the effect is minor as flow exceeds channel capacity along the length of the Vyrnwy during flood flow.

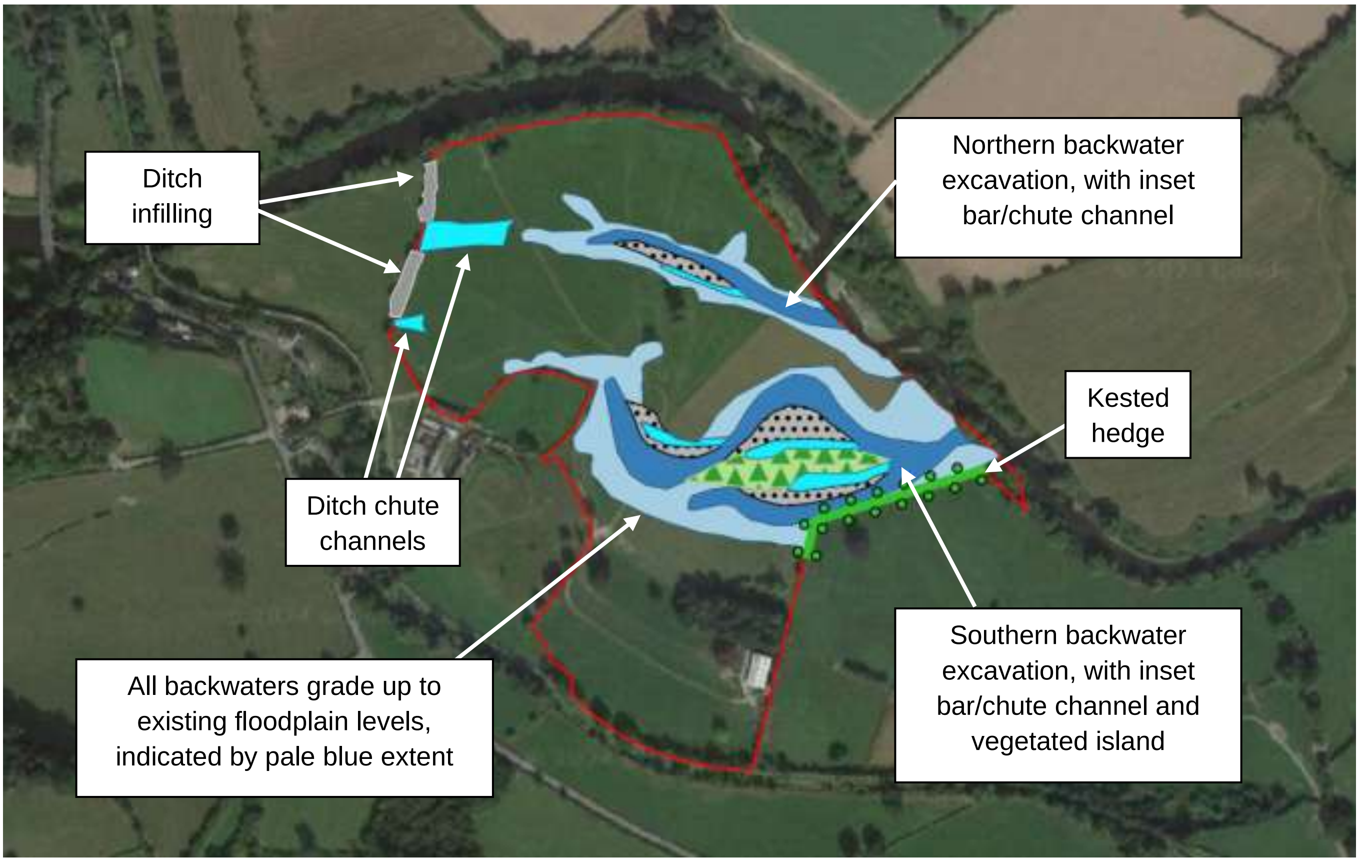


**Figure 3.6. Option 5 complex backwater arrangement comprising over-excavation of palaeochannels and diverse inset feature arrangement.**

#### 3.6.1 Impact and recommendations

- Following presentation of the option to the client team and subsequent discussion with Natural Resources Wales it was agreed to develop this option into a design given that this option works best with natural processes for the site, providing a significant complexity of habitat creation and balancing volumes of cut material against cost.

**Recommendation: Proceed to design**

## 3.7 Option 5 Revision 1

Between March and October 2024, the client held discussions with Dynamic Rivers and externally regarding the predicted habitat area provided by Option 5. Discussions considered alternative options to provide additional habitat during average summer flows. In October 2024 the client confirmed to Dynamic Rivers that funding for removal of additional material may be available, and the intention is to increase excavation for the Option 5 design. The additional funding would cover a maximum of 65,000m$^3$ excavated material and the target for suitable habitat was 250mm of ponded water during average summer flows.

Dynamic Rivers have reviewed the Option 5 layout, the concept remains comparable with the previous iteration but the bed of the backwater features has been lowered and, adjacent slopes have been adjusted to reduce the overall cut volume. Due to a boundary change supplied by the client in January 2025 the upstream section of ditch blocking and associated chute have been removed and the southern backwater ties into the existing floodplain slightly further to the east. The other ditch blocking, chutes and kested hedge remain unchanged. The Northern Backwater has been lowered to a bed level of 62.83m AOD and the larger southern backwater has been lowered to a bed level of 62.7m AOD. The option was iterated twice, first retaining the full width of the backwater bed features, this resulted in approximately 72,000m$^2$ of cut, a final iteration narrowed the backwater channels and shortened the southernmost backwater bed extent reducing cut to approximately 63,000m$^3$. The updated final design is presented in Figure 3.7.

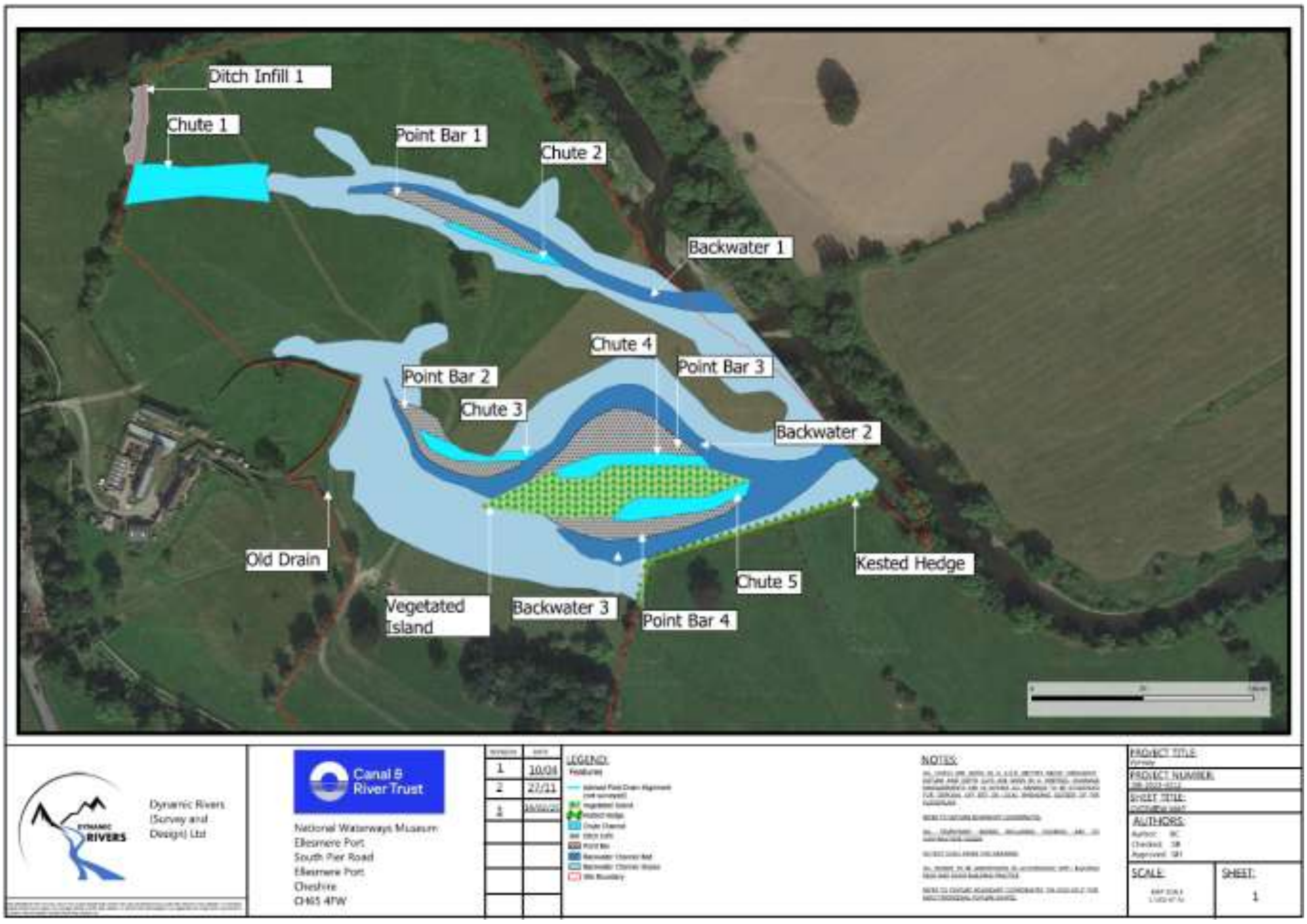


**Figure 3.7 Final Design (Option 5) Revision 1**

### 3.8 Comparison of *L. natans* habitat

Prior to agreement to pursue Option 5, the potential habitat for *L. natans* for each option was compared alongside the volume of potential arisings and presented to the client team. The results show that none of the tested options achieve 4ha of potential habitat and there is a strong positive agreement between the volume of arisings and the potential habitat availability (Figure 3.8).

As discussed with the team, the arisings are the likely main cost in all of the options and are likely to exceed the project budget in order to achieve 4ha of *L. natans* habitat. This finding further supports the choice for Option 5 which although not the smallest volume of arisings of the options developed, is by far the most naturalised, and morphologically and ecologically diverse option.

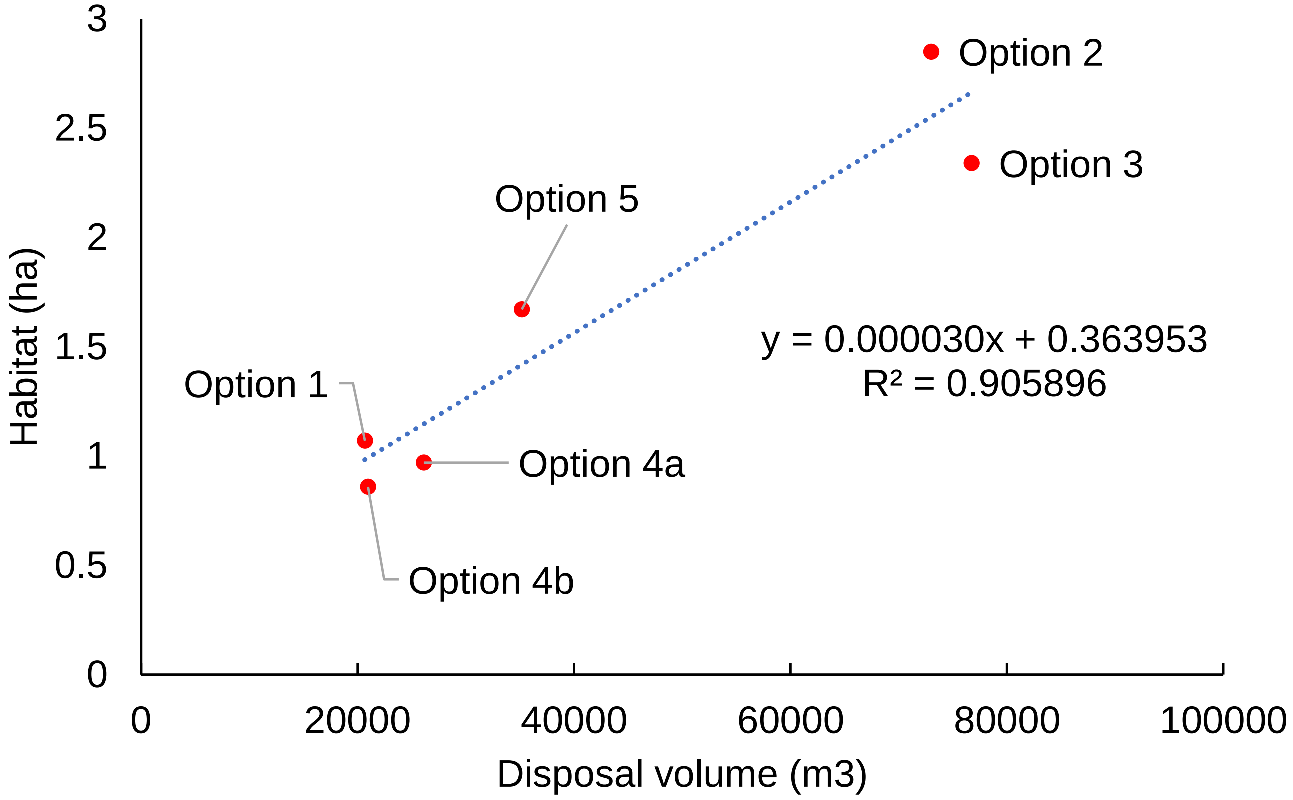


**Figure 3.8. *L. natans* predicted habitat availability compared with excavation volume. This chart was produced prior to updating the modelling with NRW data, which subsequently reduced river levels and all habitat areas will have subsequently reduced, meaning the reality of achieving 4ha at the site would require even further excavation.**

### 3.9 Modelling of final option

Flow modelling has been undertaken of the final option to inform any design iteration requirements such as managing erosion risk and establish impacts to wetting frequency and extent that could be created across the site. The final option modelled comprises the ditch blocking with chutes, backwater creation with inset features and kested hedge along the south eastern boundary.

### 3.10 2D flow model construction

To help inform the preferred option for the River Vyrnwy, a 2D HEC-RAS (v6.4) model of the study reach has been developed, using a combination of freely available LiDAR data, client supplied survey data and channel cross-section data from the Natural Resources Wales hydraulic modelling. Peak flow data was taken directly from the Llanymynech gauging station Trends Explorer using the National River Flow Archive (NRFA) website trends explorer, and hydrographs were generated using an AutoRefH approach scaled to the relevant flood peak, we have assumed this is acceptable to NRW. The model was developed at a 4m cell size for the overall domain refined to 2m for the site, Vyrnwy and surrounding floodplain. 1m refinement was initially tested however run times became unmanageable, because of the large site area and surrounding floodplain area but 2m is still considered high resolution.

The modelling has 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 through use of a flow monitoring line at the downstream extent of the model.

The model extent (also showing grid orientation) and resulting model surface is shown in Figure 3.9 below.

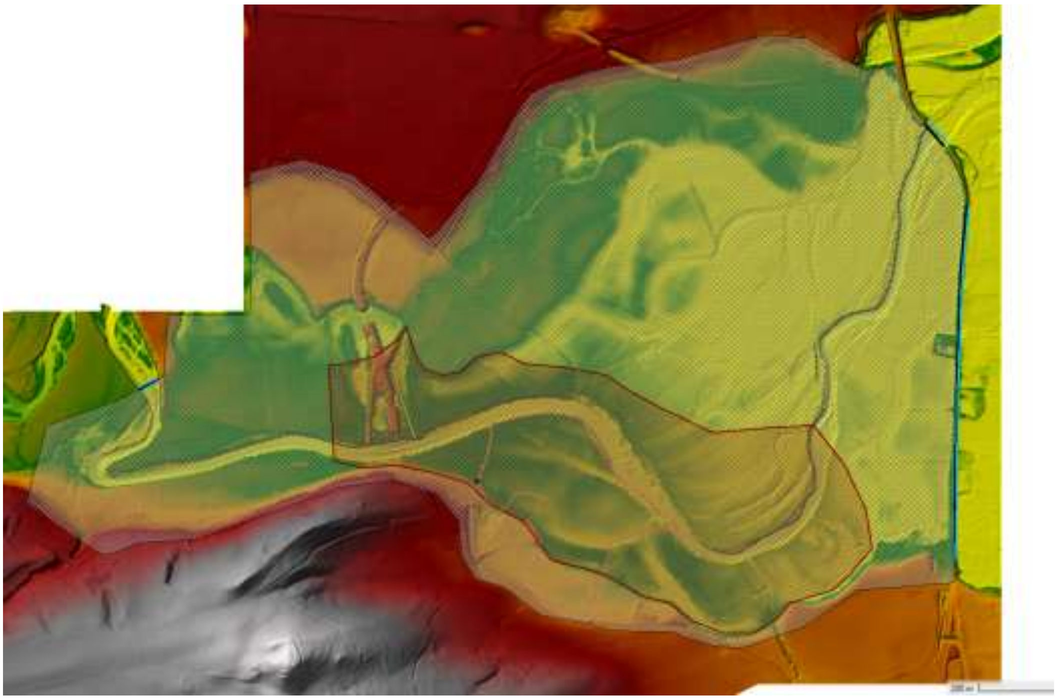

**Figure 3.9. Model extent and domain. Red polygon shows 2m refinement region within overall domain.**

### 3.11 Hydrology

Flow inputs to the upstream end of the 2D model domain for the River Vyrnwy were derived from the National River Flow Archive trends explorer for the Llanymynech gauging station, hydrograph shapes were derived from an AutoRefH (RefH2) approach with peaks scaled to the appropriate flow. The resulting flows are shown in Table 3.2 below. Summer and winter flows were also taken from the Llanymynech gauging station daily flow data. Inflows applied to the ditch have been estimated as 0.1$m^3$/s based on the field audit.

**Table 3.2. Hydrological inflows for River Vyrnwy.**

| Return Period | Flow ($m^3/s$) |
|---|---|
| Summer (Q95) | 2.35 |
| Winter (Q10) | 50.43 |
| 1 in 2yr | 328.6 |
| 1 in 20yr | 580.8 |
| 1 in 100yr + Climate Change | 1061.5 |

### 3.12 Backwater Option 5 Model Outputs

The approach to the floodplain restoration of the River Vyrnwy at the site has been to excavate large backwater features which will encourage seasonal flow connectivity, particularly winter flow. Prior to selection of Option 5, four backwater Options were tested which aimed to maximise the potential habitat availability for *L. natans.* None of those tested achieved the 4ha habitat target, and all these previous options were discounted for being less naturalised than Option 5. Within the backwater excavations there are morphological complexities comprising gravel bars, chute channels, a vegetated island and a range of different backwater side slope gradients, all providing a morphologically diverse template for potential habitat development and analogous to features seen elsewhere on the River Vyrnwy.

The Final Design produced in March 2024 only connected during winter flow, with the northern backwater feature inundating to 0.12m depth at approximately the Q10 average winter flow on the Vyrnwy. Inundation of the southern backwater to a depth of 0.1m occurred around a moderate to high Q5 winter flow. At Q5 the inundated depth in the northern backwater increased to 0.36m.

With the November 2024 updates, both backwaters inundate when flow on the Vyrnwy is 2.35$m^3/s$, a typical summer flow (Q95), shown in Figure 3.10. Modelled summer depth in both backwater features is 260mm, slightly greater than the habitat target of 250mm during summer flows. During typical winter flow, 50.4$m^3/s$ (Q10), ponded depth increases to 1.2m in the northern backwater and 1.1m in the southern backwater (Figure 3.11). During summer flow approximately 1ha of wetted area is ponded above 250mm, increasing to 2.6ha at winter flow, providing a seasonally variable open water habitat area of 1 to 2.6ha.

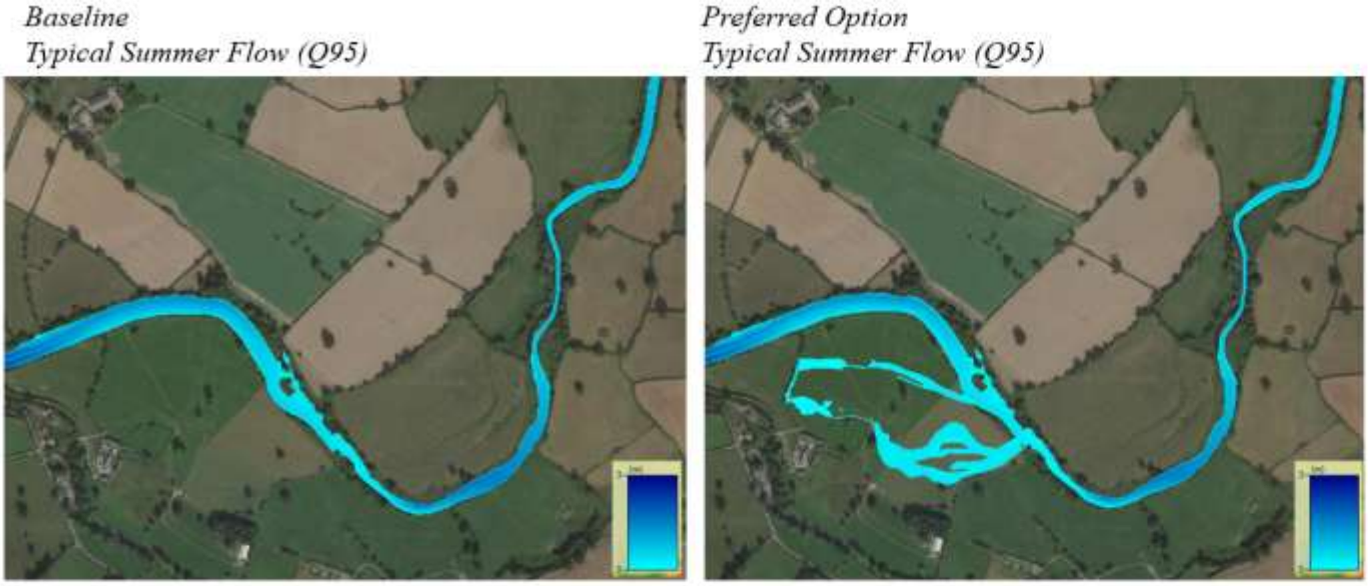


**Figure 3.10. Q95 average summer flow and Q5 high winter flow, baseline and option conditions, showing connected backwaters with ponded flow to depth of at least 250mm with the option.**

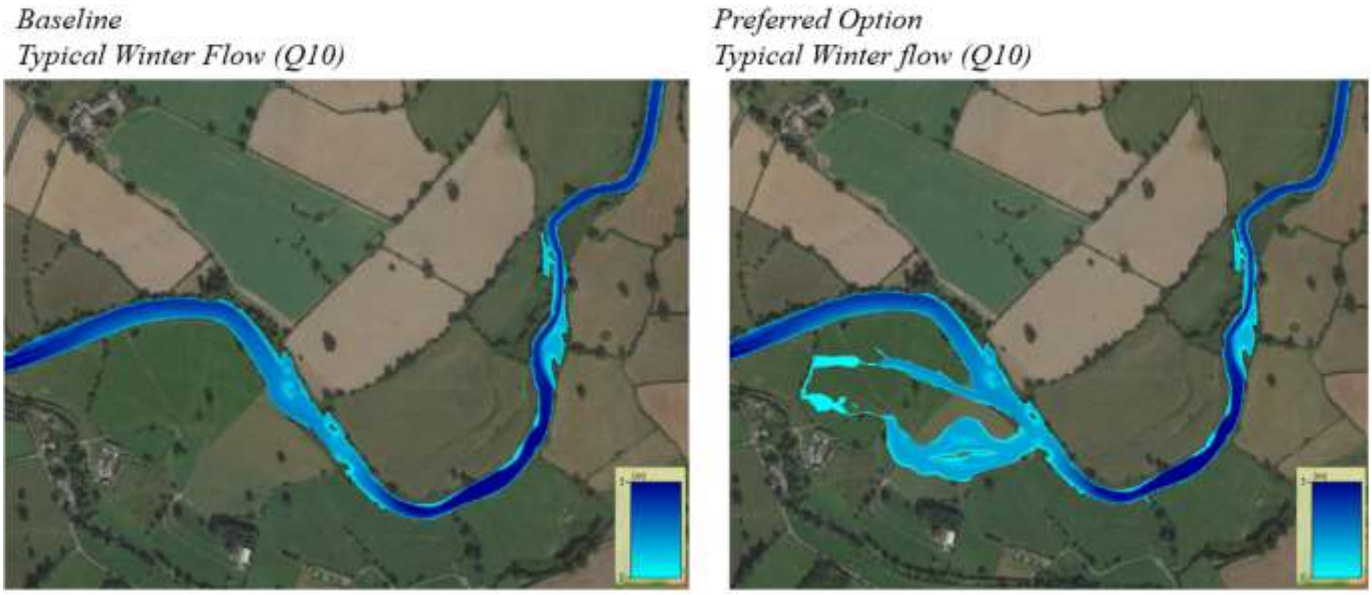


**Figure 3.11. Q10 average winter flow, baseline and option conditions, showing connected backwaters with ponded deeper ponded flow during winter conditions.**

## 3.13 Ditch blocking and chute channels

To maximise available water for inundation of the backwater features and for general increased wetting of the target floodplain area, blocking of the western ditch on site including targeted chute creation has been considered. This aims to push flow east into the floodplain and into the backwater features.

Flow modelling shows that the minor intervention associated with blocking the ditch and chute channel creation has the potential to increase surface wetness significantly (Figure 3.12), due to the spread of the flow as it exits the ditch and features that flow subsequently activates from west to east. The wetness benefit will be dependent on the volume of ditch flows that can be discharged through the chute features, which would vary seasonally and depend on canal levels and sluice operation.

During the site walkover it was noted that a baseflow entered the ditch on the western extent of the site, flow bypassed the culvert and flows into the ditch and downstream. As above, optioneering initially intended to exploit this source of flow by blocking the ditch downstream and utilising the natural west-east gradient of the floodplain at the site to encourage flow across the valley floor and towards any open water river restoration features. This source of flow would provide a critical secondary source of flow to support *L. natans* when flows from the Vyrnwy were too low to connect with the features. It would also provide a source of flow to support other wetland habitat types by increasing surface wetness of the valley floor. Subsequent discussion with the client identified the source of flow to be a leak occurring from a sluice on the canal which has since been fixed, optioneering had initially assumed this source of flow would be permanent and could help sustain the wetland. The client has since advised that leak has been fixed and that there is no longer a baseflow to the ditch. Discussion around sustaining a flow from this location via alterations to the sluice control has been undertaken between Dynamic Rivers and the client team. The outcome of discussions around the sluice is that whilst technically possible to adjust the outflow from the canal via the structure, there are significant obstacles making this not desirable and it cannot be considered within the design, these are:

- Water flowing from the sluice is likely to impact on water levels in the canal.
- Levels in the canal could be managed by taking more flow from the Tanat Feed stream to the north, this would require an abstraction licence and is an option which could be complicated by being away from the site.
- The client has identified the possibility of designing additional off takes intended to take flood flow from the canal between the Tanat Feeder and the site to mitigate flooding issues and provide flow during winter. This is technically complex particularly if works away from the site need to divert flow to the site.
- All suggested options, whilst may provide multiple benefit are not naturalised solutions and will require significant third-party discussion.

**Figure 3.12. Backwater feature inundation from ditch blocking via chute activation, estimated flow in ditches.**

### 3.14 Preferred Options and Summary

The preferred option comprises the large backwater features with inset bar, chute and vegetated island features and ditch blocking with chute channels to spill flow west to east. The restoration will function seasonally, with differing inundation depths and adjacent surface wetness occurring throughout the year. Following November 2024 changes to the design, the features will be permanently inundated to a shallow depth during summer, becoming inundated to greater depths during winter and flood flows.

The ditch blocking and chute driven surface flow is dependent on an infrequent flow source associated with the canal overflow, there will also be a very minor baseflow contribution to the ditch location. It is recommended that future hydrological management of the Montgomery Canal considers allowing a sustained baseflow through the sluice to maximise the potential surface wetness and input flow into the backwater features increasing the diversity of wetland type habitat. The inundated extents during average summer and winter flows are shown above in Figure 3.10 and 3.11, with the 1 in 2yr flood shown in Figure 3.13 and a comparison of flow change for the 1 in 2yr event monitored at the downstream end of the site is provided in Figure 3.14.

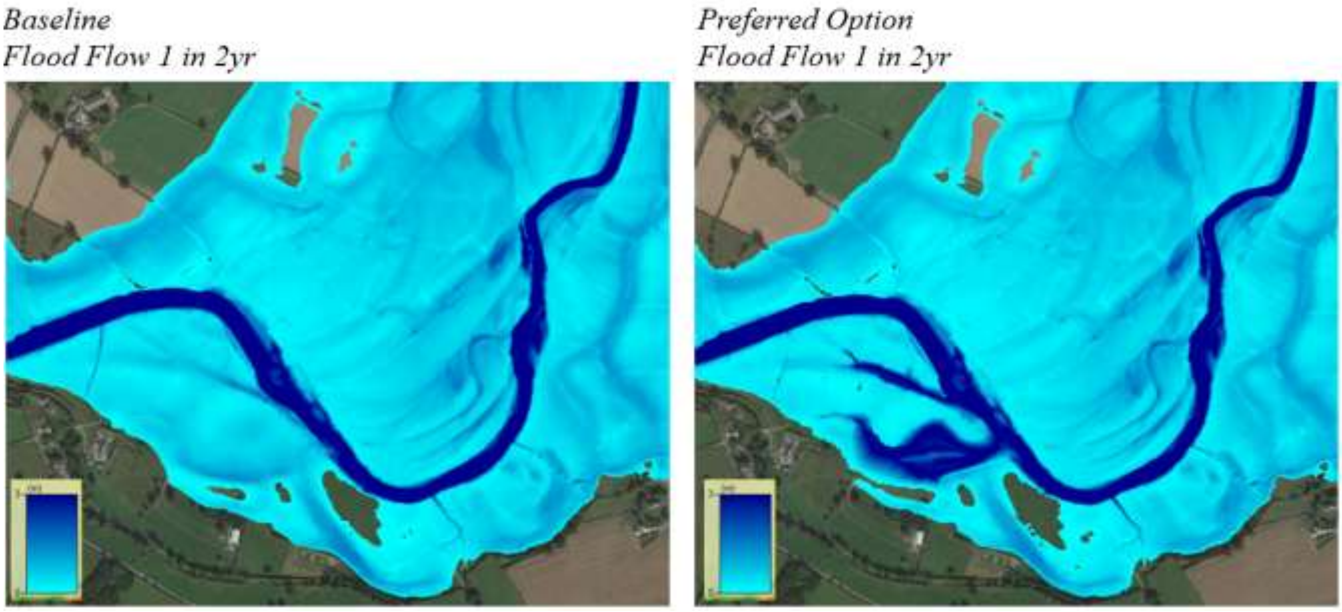


**Figure 3.13. Site flood conditions during 1 in 2yr flood – no significant changes apart from depth increases.**

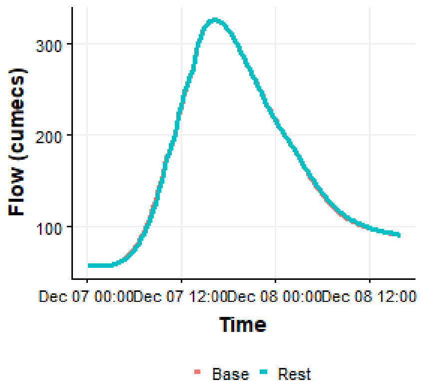


**Figure 3.14. Monitored hydrograph at downstream end of model – 1 in 2yr flow impact.**

## 3.15 Potential costs for removal of soil

Agreement to progress to design occurred prior to receipt of the most up to date bed levels from the NRW model, discussed in the modelling section below. Although unexpected, the new data was showed the modelled average summer (Q95) water levels to be around 1m lower adjacent the site than the original modelling had indicated. This results in summer and average winter flows being disconnected from the preferred option features. Features still connect at larger winter flows (as discussed above) and the backwater/paleochannel restoration is considered to function as a natural river feature, however the habitat availability for *L. natans* during summer and the majority of winter is impacted.

To better connect summer flows, discussion between Dynamic Rivers and the client considered over-excavation of the designed features. This approach has not been designed at this stage due to the ballpark costs associated with this work, summarised below:

- The existing preferred option generates a cut volume around 35,000$m^3$, understood to be close to the client construction budget.
- To over excavate a 2hectare area to achieve 1m ponded depth during summer, 2m additional vertical cut is required. This would result in an additional volume of 40,000$m^3$ more than doubling the original cut volume. Dynamic Rivers advised (email June 2024) ballpark costs would exceed £2million for this work.
- Subsequent discussion between Dynamic Rivers and Ebsford Environmental contracting (verbal and email discussion August 2024) suggest fees close to £3million for this work, note these are ballpark estimates.
- Due to the substantial costs associated with the extra excavation, Dynamic Rivers recommend investigating works in the adjacent site to the east if *L. natans* habitat availability is the guiding decision. If this site could be purchased, efforts to re-activate an area of historic paleochannel using tributary the Nant Melin could be investigated. These works are likely to be smaller in scope than works at the Vyrnwy site but provide a larger restored area of river habitat likely suitable for *L. natans*. A concept layout map for this works is provided as Appendix A, however no design work has been undertaken to support this.

For information purposes, if a lesser cut depth were to be pursued this equates to 5,000$m^3$ per 250mm, assuming 2hectare area. 2hectare approximates to the area of open water within the backwater features

# 4 Design

## 4.1 Final Option

Following liaison with the client and updates in November 2024, Figure 4.1 below shows the final design option for the River Vyrnwy site for the preferred floodplain restoration elements.

The options proposed work with the principles of floodplain reconnection, river and floodplain naturalisation, and habitat and feature improvements.

There is a field drain on site crossing the location where the features are proposed, this feature is understood to be a historic surface water drain associated with the previous hall building on adjacent land. It is proposed to sever this feature on site, should any field runoff make its way into the drain upstream from the site, this will be discharged into the features locally providing a source of minor flow.

It is proposed to re-purpose excavated gravels to form bar features within the larger backwater excavations, due to the majority of the site being within the active flood zone there are limited opportunities for spreading of material. Initial discussions with Ebsford Environmental contractors have been undertaken and disposal opportunities are being considered elsewhere, it is likely the majority of spoil will need to be disposed of at cost.

Dependent on flow volumes, topography and water levels, it could take a considerable amount of time for reconnected/created features and the floodplain to become wet following completion of the works. This is an unknown and the risk cannot be removed as part of the design process. Features and the floodplain could be drier than anticipated.

Unknown and hidden drainage could impact the functioning of reconnected areas and created features. This is an unknown and the risk cannot be removed as part of the design process. Features and the floodplain could be drier than anticipated.

If spreading of the material can be achieved on-site this must be done outside of the active flood zone area. When spreading material and tracking over any archaeologically sensitive areas (where applicable), this should be undertaken using Low Ground Pressure Plant. An archaeological watching brief may be required.

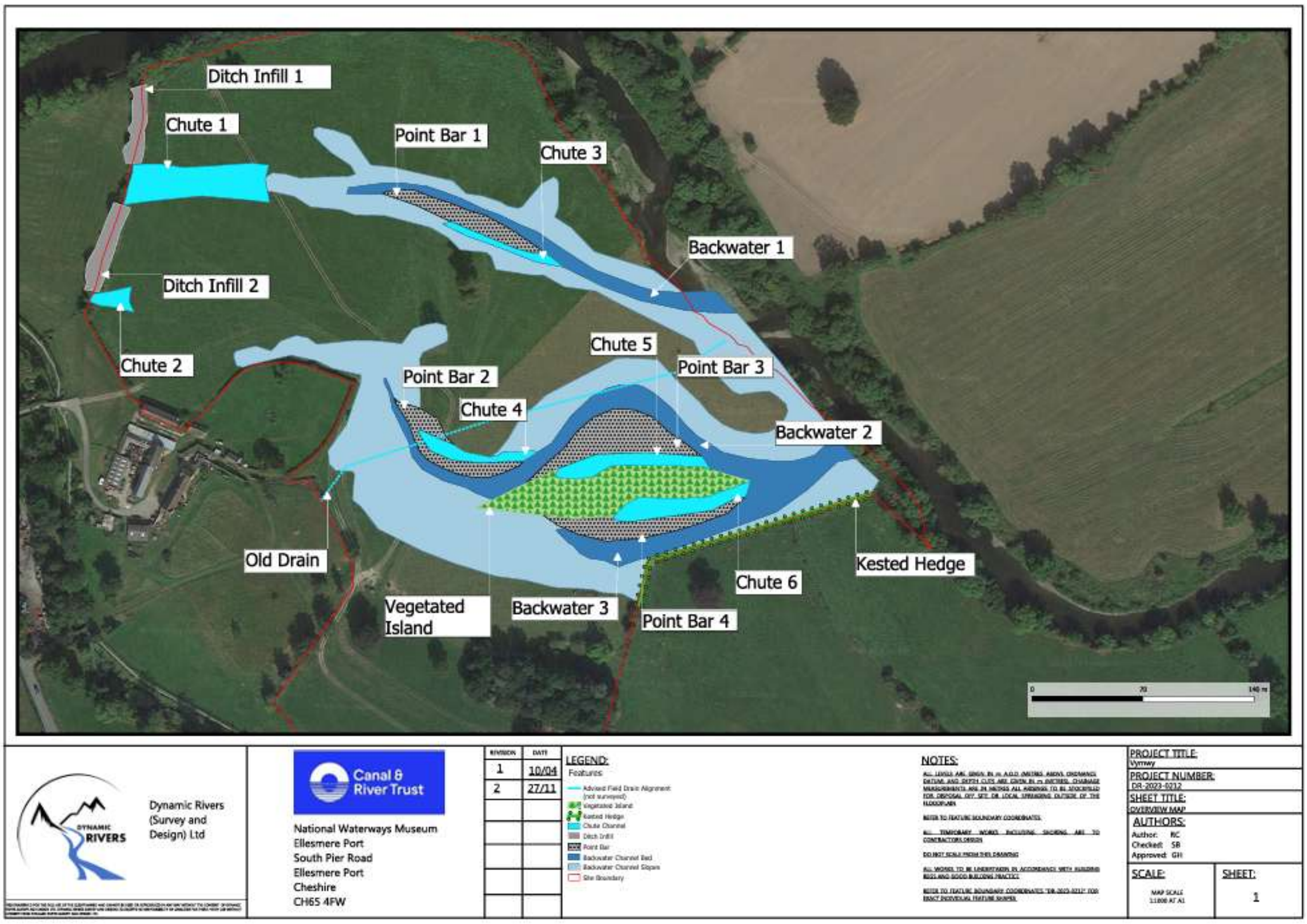


**Figure 4.1. Overview design drawing for the River Vyrnwy floodplain site.**

## 4.2 2D Flow Model Construction

To help refine the preferred design for the study reach of the River Vyrnwy, described above, a 2D HEC-RAS (v6.4) model of the study reach has been developed, using the NRW model data described in Section 3 above (it should be noted that there remains some uncertainty in levels as sedimentation and vegetation has occurred along the reach and the Vyrnwy NRW model data is likely therefore subject to some change since it was surveyed) so this may impact on predicted inundation at seasonal levels if the River Vyrnwy levels are generally higher than suggested by the NRW model, if channel levels are higher there will be an increase in the duration and frequency of inundation. This is unlikely to significantly impact material excavation volumes as the excavation is proposed within the improved grassland floodplain which is considered well represented by LiDAR levels.

Flood flow information was developed by undertaking an ungauged FEH-statistical assessment at the site, using the Llanymynech gauging station as a donor site, the full calculation record is provided within Appendix B. Low flow information was taken from the Llanymynech gauging station, representing more than 99% of the catchment area to the site location. The model was developed at a 4 m cell size and a 2 m refinement region cell size to enable suitable representation of the channel and floodplain around the site.

The purpose of the modelling was to appraise and finalise the preferred design identified above for the study areas. This enabled assessment of the impacts to in-channel processes and the hydrological regime and iteration of these features to provide the acceptable benefits. The model has also assessed the impact on flood risk both locally and downstream through use of a flow monitoring line at the downstream extent of the model.

The model has been built using a Digital Elevation Model (DEM) across the model domain that provides a ground elevation value for each grid cell. The model extent (also showing grid orientation) and resulting model surface for the proposed options is shown in Figure 4.2 below.

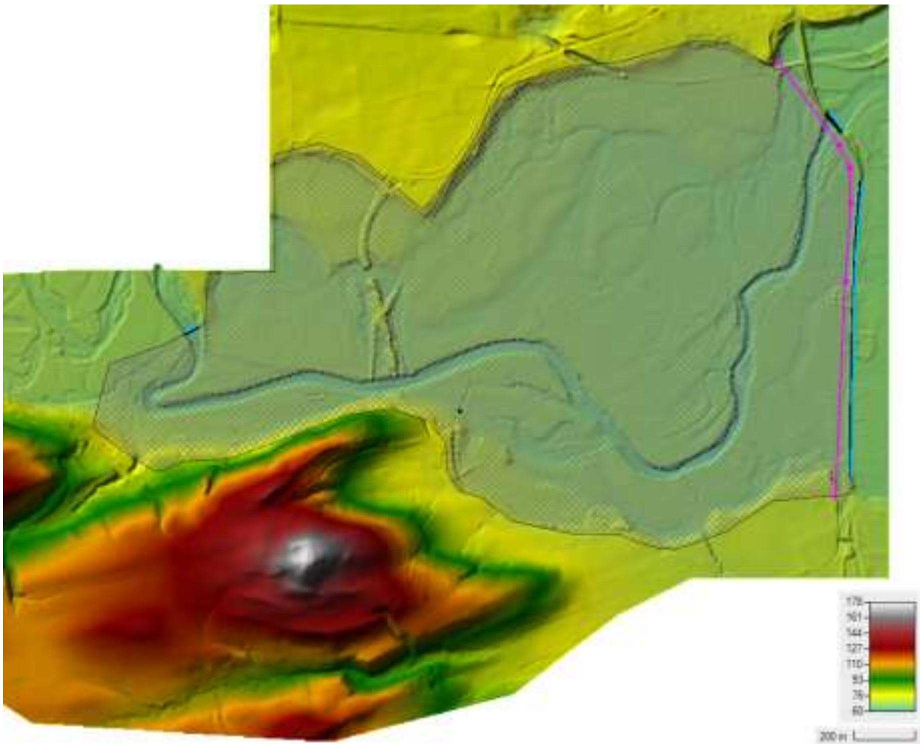

**Figure 4.2. Final model extent for the River Vyrnwy study reach.**

### 4.3 Model Bed Level Discrepancy

The optioneering work was undertaken whilst waiting for NRW to supply the correct hydraulic model data. There are two models for the area, the River Vyrnwy hydraulic model (MWH 2015) and the Severn/Vyrnwy Confluence hydraulic model (JBA Consulting 2011). The River Vyrnwy hydraulic model ends approximately half way down the site, just upstream of the gravel bars in the river and the Severn/Vyrnwy confluence hydraulic model covers the full site to downstream boundary model location. NRW originally supplied the River Vyrnwy model only, so bed levels downstream from the gravel bar locations through to the downstream boundary were estimated by adjusting the LiDAR bed levels by the average difference in bed level between LiDAR and the River Vyrnwy model bed levels, which was considered a fair assumption at the time.

Optioneering and steering group discussion eventually confirmed a final design which provided ponded water at 1m depth during target flow conditions, however this was based on the Vyrnwy Model and bed level assumptions. When NRW later supplied the Severn/Vyrnwy confluence model the bed levels from the NRW model were extracted and incorporated into the Dynamic Rivers model. These levels were lower than anticipated and once the models had been simulated and results reviewed, showed a general reduction in modelled water level of 1m towards the downstream extent of the site, which results in disconnecting the features during summer flow. The final design remains consisted but flow from the River Vyrnwy now connects at approximately a Q5 winter flow (approximately 18 days a year). This flow connection frequency is still considered to function more naturally than a large pond type feature, however *L. natans* habitat may be compromised particularly below winter flow.

### 4.4 Model Run Parameters

Default parameters were used in the 2D HEC-RAS model setup. 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. The downstream boundary of the model is a normal depth boundary, with the rating calculated using the underlying model surface information.

Manning's 'n' roughness values

Manning's 'n' roughness coefficients have been applied to the 2D model surface and have been informed through published information with regards to appropriate roughness values[1]. These values are (Table 4.1):

**Table 4.1. Model roughness values**

| Model domain feature | Manning's 'n' value |
|---|---|
| Open channel – moderate energy river system with some in-channel roughness | 0.045 |
| Floodplain – some high grass and light brush/vegetation cover, generally similar across whole model domain. Lots of improved grassland | 0.045 |

### 4.5 Hydrology

Flood flow inputs to the upstream end of the 2D model domain for the River Vyrnwy were developed using an FEH-statistical and ReFH2 assessment, documented within Appendix B. Low flow values were taken from the Llanymynech gauging station. For the purposes of this modelling assessment, a 1 in 100yr plus allowances (25% uplift[2]) 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), again taken from the NRFA gauge information for the Llanymynech gauging station. The corresponding flows were:

River Vyrnwy flows:

- 1 in 100yrCC – 673.9$m^3/s$
- 1 in 20yr – 400.7 $m^3/s$
- 1 in 2yr – 235.3 $m^3/s$
- Q95 – 2.35 $m^3/s$

[1] Chow, V.T. (1959) Open Channel Hydraulics. McGraw-Hill, New York

- Q10 – 50.43 $m^3/s$

Additional flood flow return periods were simulated to support the Flood Consequences Assessment which should be read in conjunction with this report these are:

River Vyrnwy flows:

1 in 100yr – 539.1 $m^3/s$

1 in 1000yr – 891.1$m^3/s$

1 in 1000yrCC – 1113.9$m^3/s$

### 4.6 Utility information

A services search has been conducted/provided for the site by the client and those supplied are shown in the design drawings against the proposed design. 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. Service searches could be incomplete. Dynamic Rivers accept no liability for the presence of services on site.

No utilities are likely to be directly impacted by the proposed works. However, there is an existing field drain crossing the site, this feature will be broken out/ severed as part of the proposed excavation works for the scheme. Other services may be crossed under or over during the excavation works and contractor should be aware of their presence.

There are utilities following the local road networks which contractors should be aware of if tracking over with heavy machinery.

A services search should be undertaken prior to works commencing 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, with appropriate liaison with the service provider. 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 undertake a C.A.T4 / radio-detection scan, in liaison with the provider, and locate these services prior to excavation commencing if deemed required.

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 its presence and work with limiters. They should also locate any buried services before excavation begins in liaison with the service provider. Track mats may be required across buried services.

There is one known land drain pipe crossing the site, the alignment of this drain has been assumed based on on-site manholes. The design includes severing this structure to allow any flow to spill into the features as well as reducing the efficiency of fine sediment transport for the structure into the Vyrnwy. It has been assumed that this land drain can be broken without consequence and it is understood that the client is seeking landowner approval for these works which should be agreed prior to construction. Dynamic Rivers accept no liability or responsibility for any services present or impacted as a result of any works undertaken on site.

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.

Service searches do not always show manhole presence. There is a risk of water flowing across manholes and underground services more frequently, and to greater depths, as a result of floodplain reconnection works. Wetter floodplain areas also may occur around overhead services. Pylon locations are not always plotted on supplied service searches. This could mean that some pylons have been missed. This should be reviewed by the contractor on site prior to works commencing.

## 4.7 Final Design

The preferred restoration design option is shown in Figure 4.1 above following liaison with the client. Detailed design drawings have been produced alongside a Method Statement that outlines how a contractor might 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 been undertaken to understand the influence of the proposed design, wetting impact as a result of the preferred restoration scheme, and the flood risk impacts as a result of the preferred scheme design.

## 4.8 Bed Shear Stress

Baseline bed shear stress model outputs show that generally under extreme flows values range between 20-80 N/m$^2$ (Figure 3.21) within the River Vyrnwy channel study reach, with higher shear stresses through the reach upstream from the site where the channel is narrower and straighter. Across the floodplain, shear stresses reach around 20-30 N/m$^2$ but are generally much lower. Within the feature locations, shear stress is typically <10 N/m$^2$ under baseline conditions and there are negligible changes with the restoration features considered. There is a very minor increase to shear stress in-channel local to the connection of the southern backwater feature for the 1 in 100yr plus climate change event (Figure 4.4) and for the low order 2yr flood event, but this is considered minor and is due to the significant wetted area under baseline conditions (Figure 4.4 and Figure 4.5). This increase occurs on the falling limb of the hydrograph as ponded flows recede, the increase is only 10-20 N/m$^2$ over 30-40 N/m$^2$ at the location and remain well within typical values for the overall reach, however this is likely to locally influence patterns of erosion and deposition within the channel as part of natural processes over time.

Most cohesive soils, especially when vegetated, resist over 100 N/m$^2$ and outputs show that we are generally within this range (typically less than 10 N/m$^2$) for both lower and higher order flows across the floodplain (Figure 4.4 and Figure 4.5). However, flow concentration will still instigate low level headcutting as part of natural processes associated with floodplain reconnection, chute channels and associated development. Gravels/cobbles and fine sediments are likely to deposit within the channel (as they do currently) at a slightly greater rate due to the improved floodplain connectivity, and across reconnected backwaters more readily. At the point downstream from the large backwater, deposition may occur at a slightly reduced rate due to the minor increase in shear stress. This is part of natural processes and is encouraged as part of the scheme. The backwaters created are low energy features and may be subject to some infilling over time, again this is a natural process for features of this type and is part of the evolution of the floodplain area. These features will be seasonally wet, although may retain water all year round dependent on rainfall and any flow from the ditch to the west of the site. Natural processes and associated erosion and deposition may change the flood regime and pattern over time. This should be continued to be monitored as part of a monitoring programme following construction.

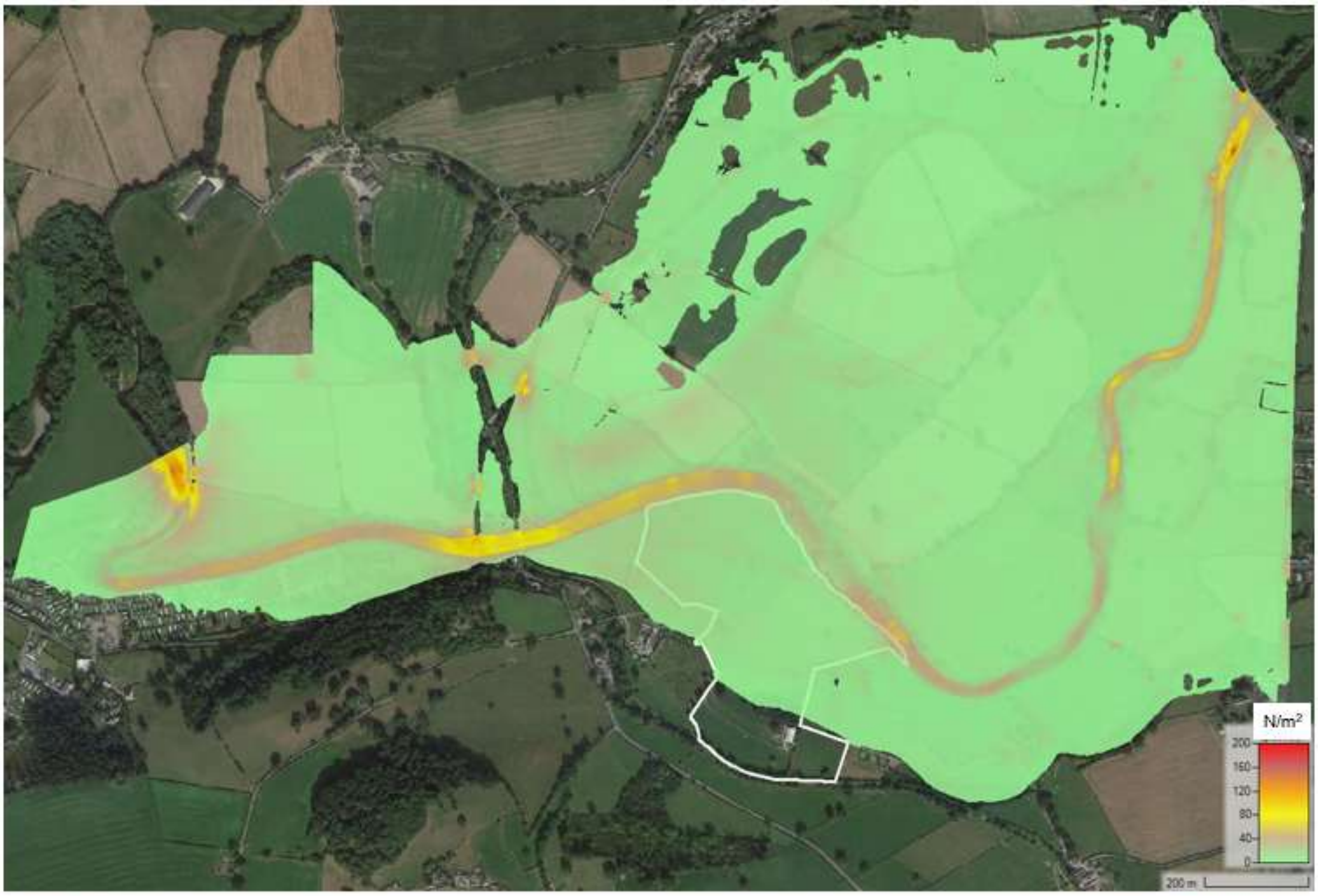



**Figure 4.4. Predicted extreme shear stress (N/m$^2$) levels across the baseline (TOP) and restored (BOTTOM) scenario along the River Vyrnwy study reach.**

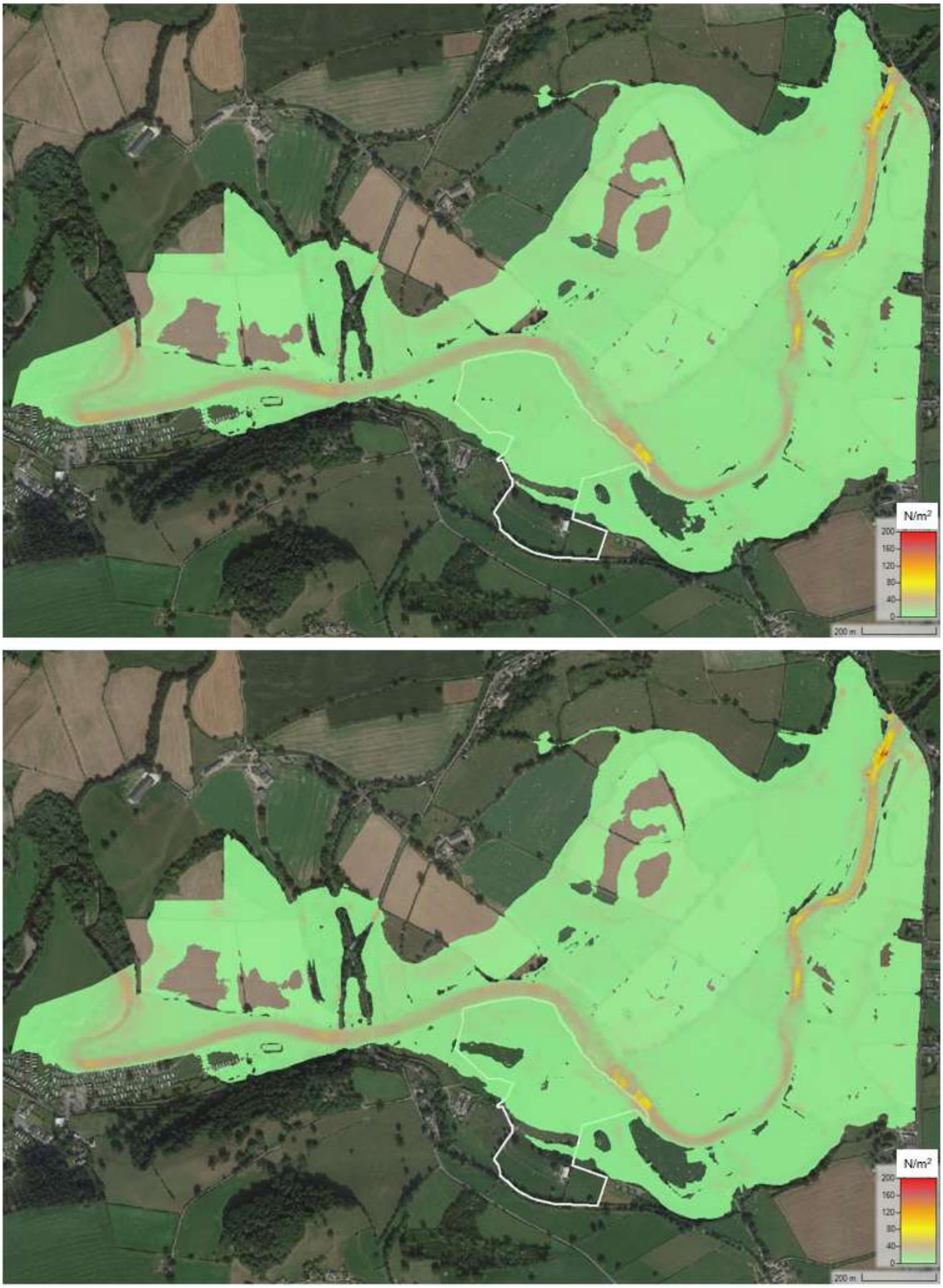


**Figure 4.5. Predicted low order flood shear stress ($N/m^2$) levels across the baseline (left) and restored (right) scenario along the River Vyrnwy study reach.**

## 4.9 Predicted habitat development

Dynamic Rivers have undertaken a predicted wet floodplain habitat assessment into areas of floodplain which could potentially develop into functional wet grassland, fen/mire or other wetland type habitat using the floodplain wetting tolerance ranges suggested by Wheeler et al. (2004)[3]. Due to the disconnection of summer flows within the River Vyrnwy from the floodplain at the site, it is unlikely that a diverse mix of valley floor wetland habitat will develop, due to the over-dry floodplain. The tool did indicate that the margins of the backwater could potentially develop into swamp type habitat. *L. natans* may succeed within the initial stages of swamp habitat development, but there is a risk of out-competition by other swamp preferential species as part of natural biotic processes and it is unlikely to survive due to succession without intervention (management).

## 4.10 Flood Risk

Flood modelling for the current and restored site scenarios has been undertaken to determine the fluvial flood risk impacts as a result of the proposed scheme along the River Vyrnwy. This has been undertaken for the 1 in 100yr plus allowances for climate change, 1 in 20yr and 1 in 2yr return period flows. Low flows and associated restoration impacts are discussed in the section above with to preferred option selection.

Figures 4.6 to 4.8 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).

There are no notable changes in flood extents for the 1 in 100yr plus allowances for climate change (Figure 4.6) and 1 in 20yr events (Figure 4.7) due to the significant flooded area already occurring under baseline conditions and introduced features generally being drowned out under these flow conditions. Figure 4.8 shows some very localised changes in flood extent for the lower order 1 in 2yr event, mainly due to the additional capacity within the floodplain associated with the excavation of backwater features, but the difference is minor and localised to the site and features. Flood water depths will be greater in excavated features compared to baseline for all modelled return periods.

The flooding regime could change over time as the river and floodplain naturalises and responds to the proposed works. This is part of natural processes. Any excess spoil will need to be spread elsewhere out of active flood zone areas or removed from site. There will be a period of time where works are partly complete. If a flood were to occur at this point during the construction, then unpredicted flooding could occur. This risk cannot be removed as part of the design process.

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[3] Wheeler, B.D., Gowing, D.J.G., Shaw, S.C., Mountford, J.O. and Money, R.P., 2004. Ecohydrological guidelines for lowland wetland plant communities - gean0205bipz-e-e.pdf (publishing.service.gov.uk)

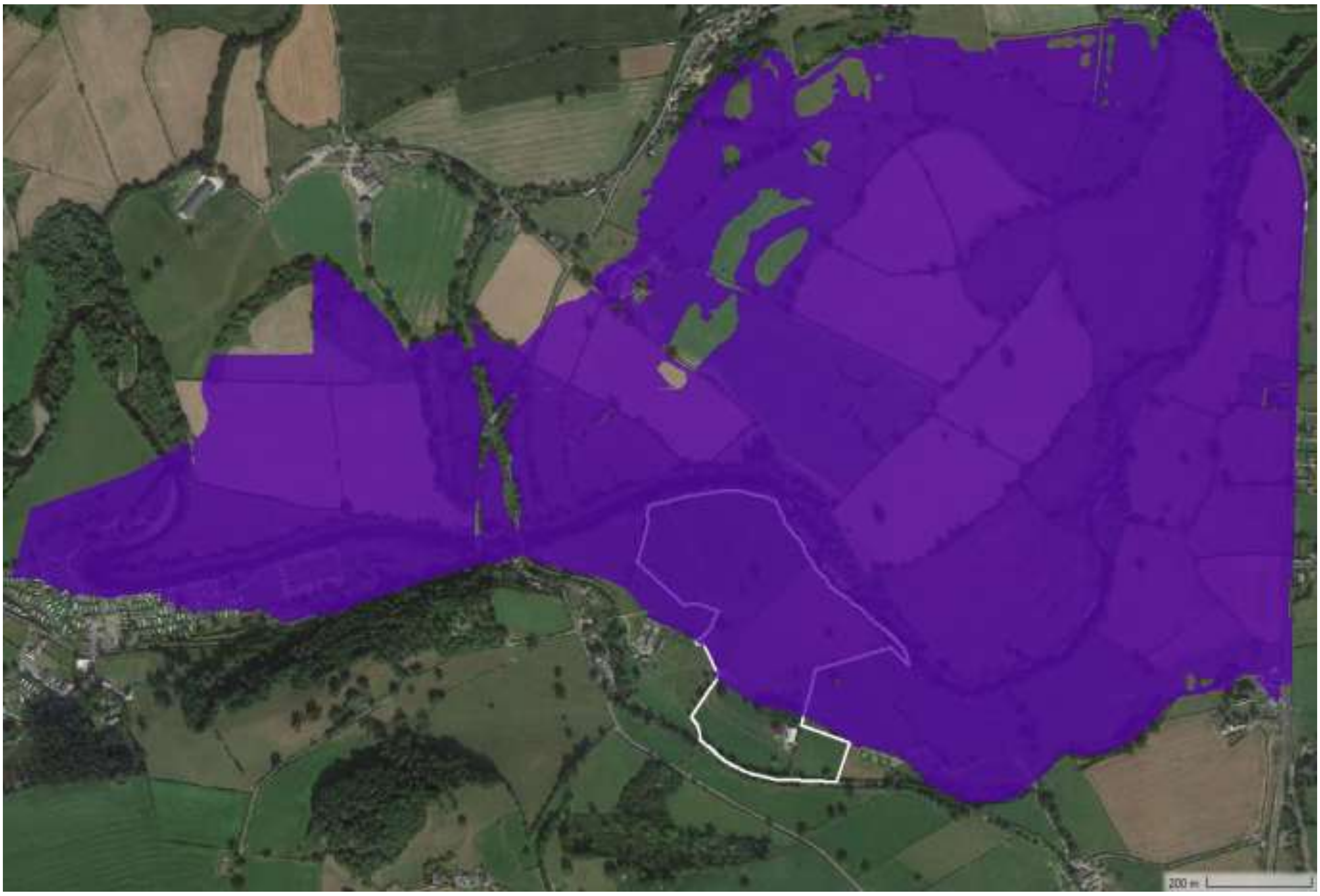


**Figure 4.6. 1 in 100yrCC flood extent change for modelled scenario, blue = baseline, red = restored (where red is visible indicates flood extent increase compared to baseline, purple indicates no change and blue indicates reduction in flood extent).**

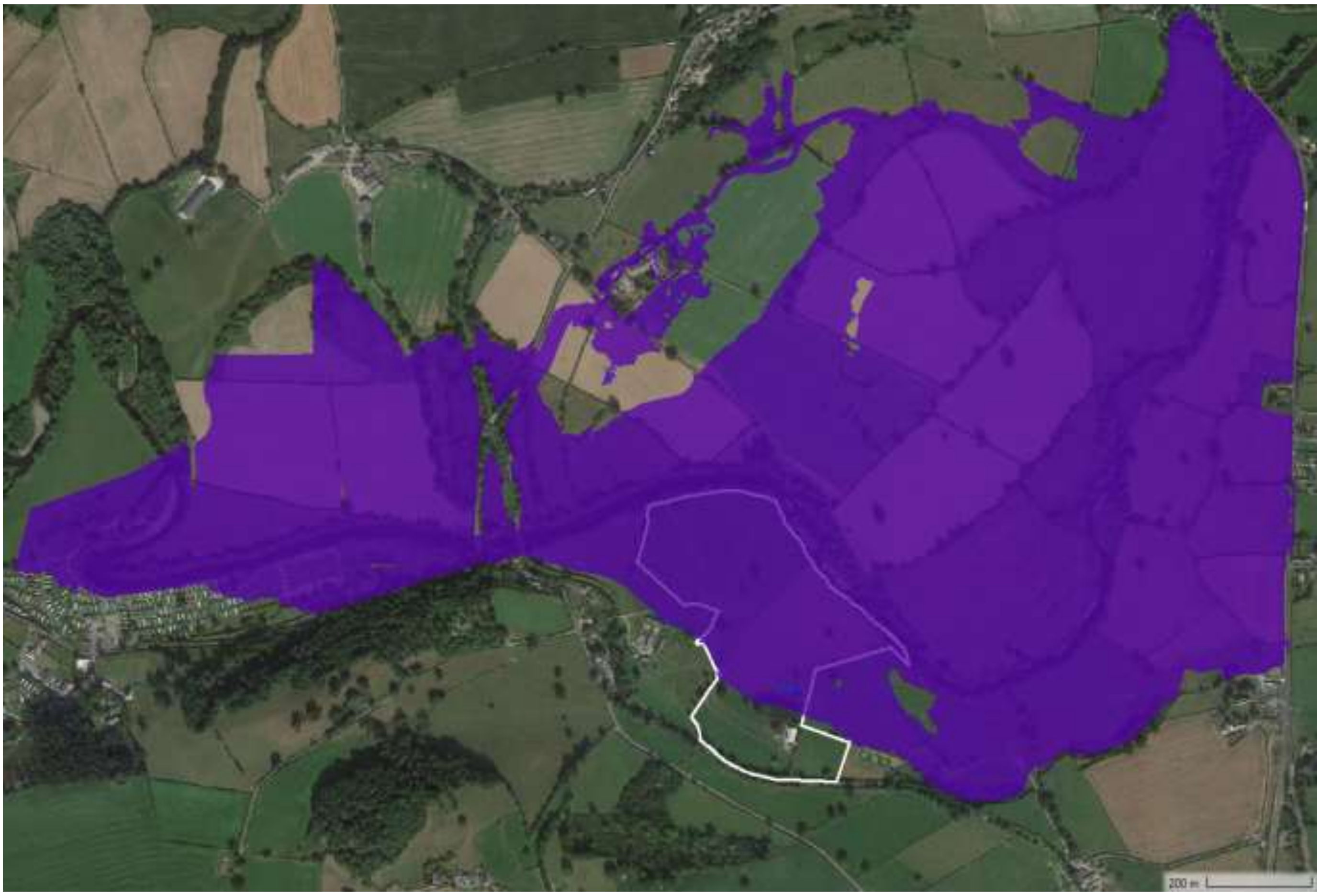


**Figure 4.7. 1 in 20yr flood extent change for modelled scenario, blue = baseline, red = restored (where red is visible indicates flood extent increase compared to baseline, purple indicates no change and blue indicates reduction in flood extent).**

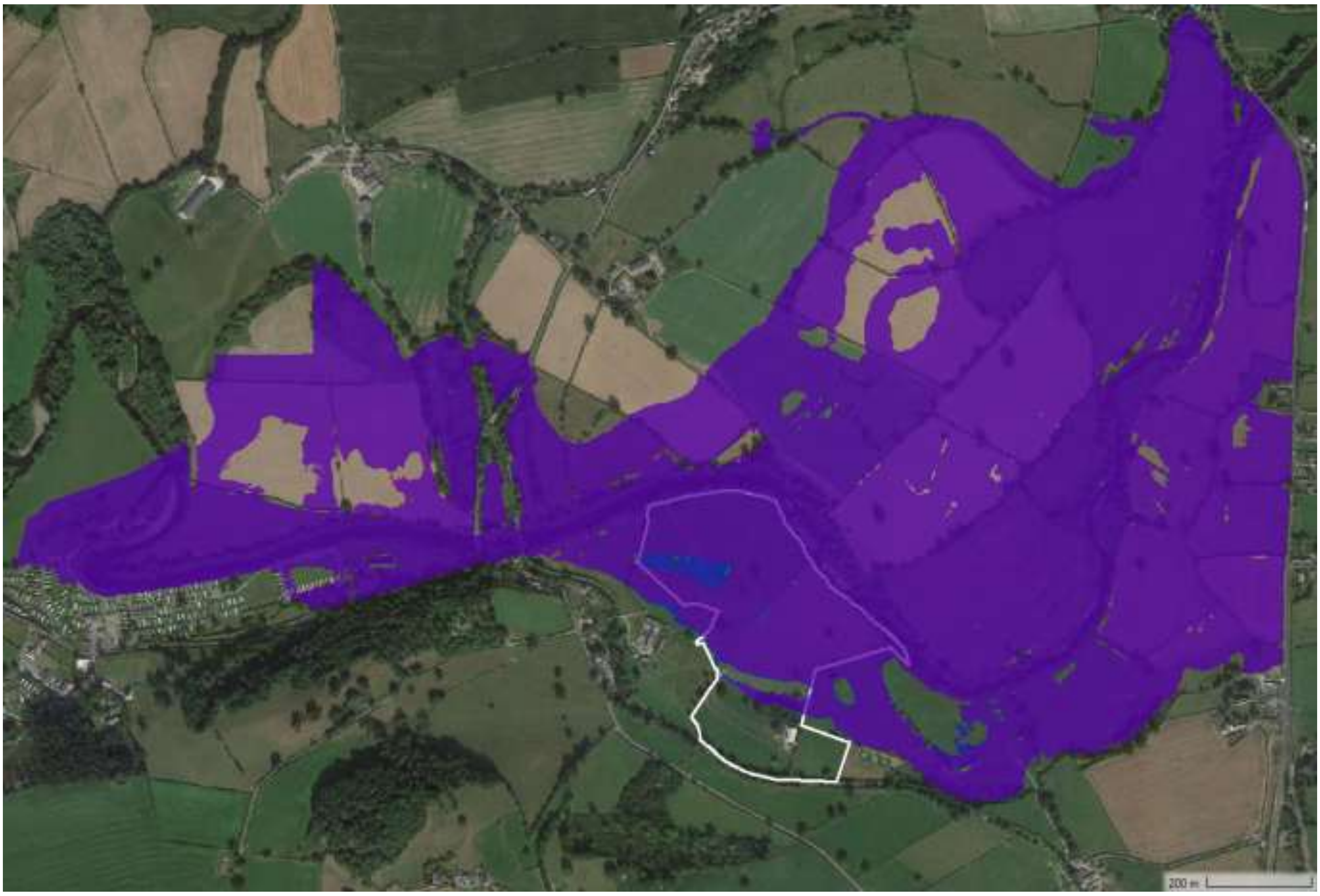



**Figure 4.8. 1 in 2yr flood extent change for modelled scenario, blue = baseline, red = restored (where red is visible indicates flood extent increase compared to baseline, purple indicates no change and blue indicates reduction in flood extent).**

Downstream (flow monitored at the downstream end of the model), the impact of the proposed works for the 1 in 100yrCC, 1 in 20yr and 1 in 2yr events is negligible in terms of the peak hydrograph flow (Figures 4.9 to 4.11). There is negligible change to the hydrograph shape and peak flow, therefore there is no significant modelled increase in downstream flood risk as a result of the proposed restoration works.

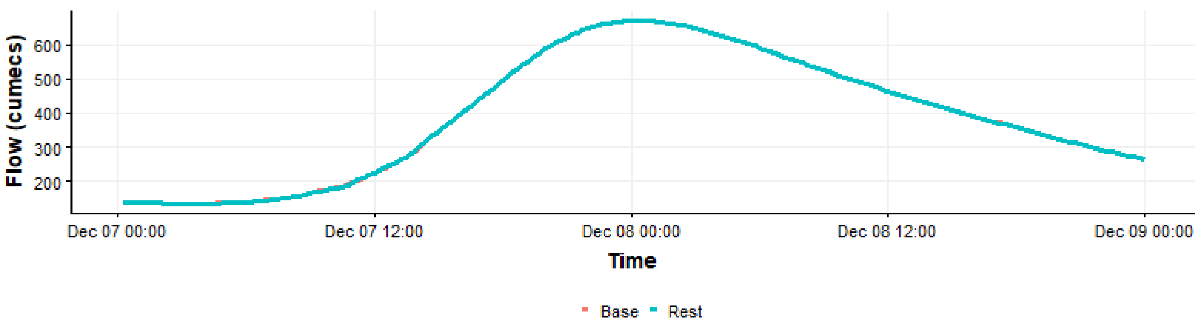



**Figure 4.10. Downstream flood hydrograph change for the 1 in 100yrCC baseline and restored scenario.**

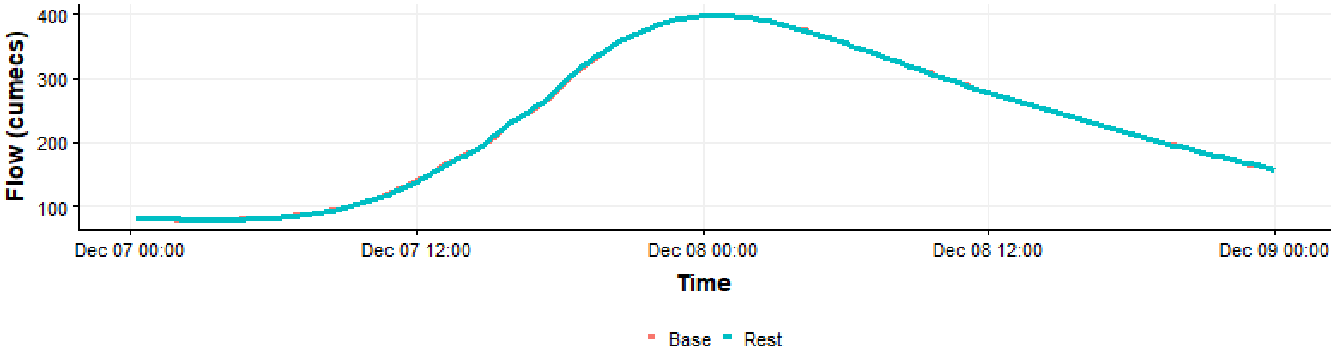



**Figure 4.11. Downstream flood hydrograph change for the 1 in 20yr baseline and restored scenario.**

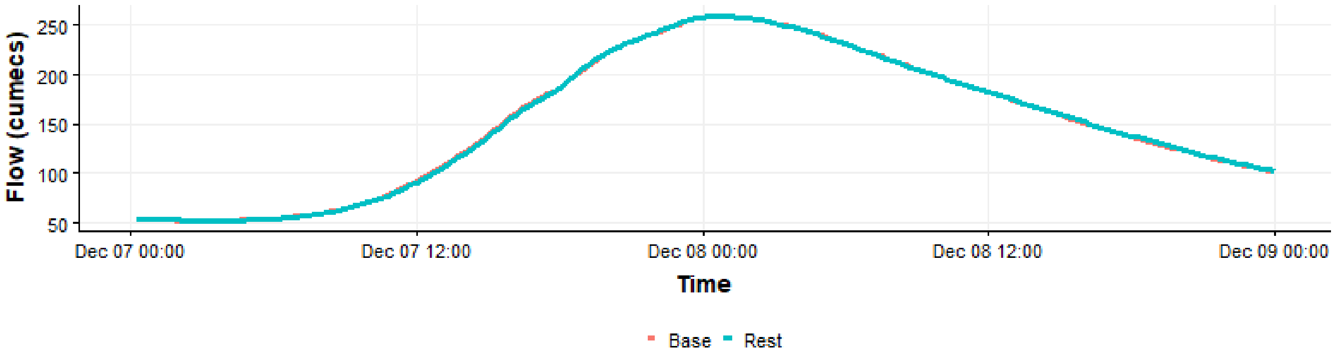



**Figure 4.12. Downstream flood hydrograph change for the 1 in 2yr baseline and restored scenario.**

## 4.11 Residual flood risk and gauging station concerns

*Downstream Boundary*

NRW pre-application comments were received by the Canal and River Trust in December 2024 and provided to Dynamic Rivers in January 2025. Within the comments there was a query relating to the location and approach to downstream model boundary. The boundary location has been specified here as it is an embanked section of road, i.e. an existing break within floodplain hydraulics which causes flow to back up and provides a sensible location for a downstream boundary. The simple backwater calculation taken from Chapter 7 of the EA Fluvial Design Guide4 is 0.7 x depth / slope, the bankfull depth near the downstream boundary location is 3.06m and the channel gradient varies from 0.00125m/m 0.000136m/m. Taking the lowest value of gradient this is equivalent to a backwater distance of 15.75km.

Constructing a hydraulic model of 15.75km to assess the relative changes associated with a net excavation of material from the flood zone is considered a disproportionate model extent for the assessment. The downstream boundary is already 1.5km further downstream from the site. Ultimately an additional 15km model length would result in major increases to model run times with potential project delay and potential additional costs to the client.

[4] https://www.gov.uk/flood-and-coastal-erosion-risk-management-research-reports/fluvial-design-guide

For the model build a gradient of 0.001m/m (1 in 1000m) has been adopted for the downstream boundary as is generally representative of the low gradient River Vyrnwy towards the location of the downstream model boundary. To investigate the influence on water levels at the downstream extent of the site related to the choice in downstream boundary, a sensitivity test on the gradient applied to the boundary was undertaken. The test involves varying the gradient applied to the downstream boundary condition by +/- 20%, i.e. a significant change, to assess any significant change in water level. The test was simulated for both baseline and proposed restoration site conditions, the results of the assessment are shown in Table 4.2.

**Table 4.2. Changes to modelled water level for the baseline and proposed option scenario at the downstream extent of the site. Based on varying downstream boundary gradient +/-10%.**

| Description | 1% AEP CC |
|---|---|
| Downstream Baseline (normal conditions) | 66.28 |
| Downstream Baseline (-20% slope DS boundary) | 66.33 |
| Downstream Baseline (+20% slope DS boundary) | 66.24 |
| Downstream Restored | 66.29 |
| Downstream Baseline (-20% slope DS boundary) | 66.35 |
| Downstream Baseline (+20% slope DS boundary) | 66.25 |

The results in Table 4.2 show that whilst varying the downstream boundary gradient has an influence on water levels at the site, this influence is minimal <100mm change across both +/- change and normal slope scenarios. Furthermore, the change in water levels is comparable between baseline and the proposed option scenario and therefore the choice of boundary condition is not considered to be more significant for flood risk assessment for either baseline or proposed site conditions. To reiterate, the proposed site once constructed will provide a minor localised increase in flood storage and will not be accessed by the public. Due to the wide range of modelled return periods simulated to support this FCA, there is confidence that minor sensitivity to the downstream boundary location does not affect the assessment of flood risk at the site.

*Llanymynech gauging station*

NRW also recommended the need to demonstrate that there is no negative backwater affect from the restoration proposal which could affect gauging performance of the Llanymynech station.

The proposed restoration involves a net removal of material from the floodplain downstream from the location of the Llanymynech gauging station. Changes to normal water levels within the River Vyrnwy will be negligible post-construction as the option does not raise the bed level above the existing water table. The main hydraulic control i.e. influence on backwater at the Llanymynech gauge is the Montgomery canal (aqueduct) and the adjacent road bridge, which cause flow to back up during floods, neither of these existing structures will be modified as a result of the restoration works. A comparison of modelled water levels at the location of the Llanymynech gauge (approximate grid reference: 325294 E, 319610 N) for low flow (Q95 summer and Q10 winter) through to flood flow (2yr to 1000yr) is presented in Table 4.3 and Figure 4.13, both the table and graph illustrate no change to water levels across a full range of flows at the gauge location.

**Table 4.3. Modelled water levels for baseline and proposed restoration conditions at the Llanymynech gauging station location.**

| Return period | Notation | Flow | Water level baseline (m AOD) | Water level option (m AOD) |
|---|---|---|---|---|
| 0.05 | Q95 | 2.44 | 63.13 | 63.13 |
| 0.1 | Q10 | 50.53 | 64.42 | 64.42 |
| 2 | 2yr | 235.5 | 66.39 | 66.39 |
| 20 | 20yr | 400.7 | 66.74 | 66.74 |
| 100 | 100yr | 539.1 | 67.04 | 67.04 |
| 1000 | 1000yr | 891.1 | 67.60 | 67.60 |

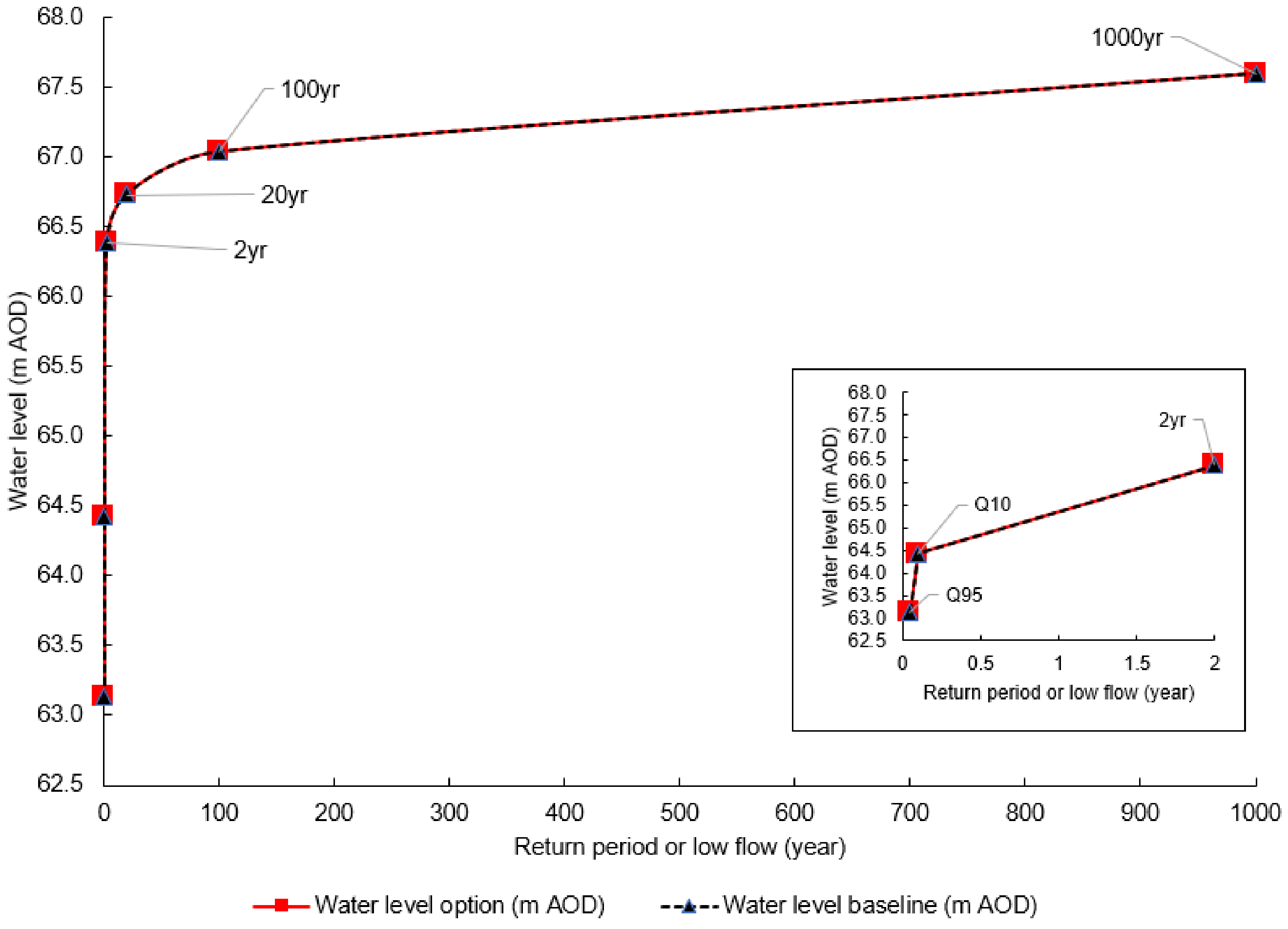



**Figure 4.13 Comparison of modelled water levels at the Llanymynech gauging station. Low flows to QMED (2yr) inset on smaller graph for legibility.**

# 5 Conclusions and Recommendations

## 5.1 Conclusions

- Canal & River Trust commissioned Dynamic Rivers to undertake river and floodplain restoration along River Vyrnwy using process-based principles that will create dynamic backwater features and the river and floodplain to function more naturally. A ditch to the west of the site will be blocked at present no flow will go down this ditch but future client about hydrological management of the Montgomery Canal could be pursued and the sluice feeding this ditch could be exploited to maximise potential wetted habitat throughout the year.
- The River Vyrnwy is generally an active single thread, gravel/cobble river with a moderate gradient, with evidence of extensive floodplain reworking preserved in the landscape. It has been modified in the past and displays evidence of channel straightening to the west of the study site. Activity levels at the study site appear reduced with little change to the planform of the river between the 1880 Ordnance Survey map and present. However, there are sinuous reaches in the locality of the study reach and where the channel becomes generally more laterally active with clear evidence of channel bar growth and riffle/rapid presence. The development of the sinuous reach within the study area is further demonstrated in historic Google Earth imagery and demonstrates that increased deposition in the channel will result in local erosion and impacts to in-channel processes.
- Two main naturalisation options comprising backwater creation and ditch blocking are proposed to provide river restoration and habitat creation, within these overarching approaches there are additional features to provide dynamism. These include:
    - Chute driven floodplain flow from the western ditch, intermittent flow dependent on supplied flow to ditch;
    - Bar features with chute channels inset;
    - An island to allow natural vegetation succession;
    - Variable slopes to provide structural complexity of backwater features;
    - Chute driven backwater flow into gravel bars;
    - Sinuosity within backwater channels;
    - A kested hedge to provide naturalised terrestrial vegetation;
    - Over-excavation of palaeo channel locations.
- The approach to the restoration at the River Vyrnwy has been large scale excavation with smaller features inset into larger backwater features. Large scale excavation is required to ensure that flow connectivity to the River Vyrnwy is possible at winter flows. To ensure the river restoration functions naturally the reach downstream from the site with bar and backwater development has been utilised to provide an analogue. Although the backwater features are larger in extent than those developing downstream, they are characteristic of the River Vyrnwy. Ditch infilling and chute driven floodplain and feature activation provides another potential source of flow into the features, although this will be infrequent, future hydrological management of the Montgomery canal sluice which feeds this ditch could exploit this sluice to maximise flows into the ditch and restoration features.

- The backwater features created as a result of these options will result in a medium-term change to the sediment regime, this will be localised to downstream from the features within the Vyrnwy caused by a change in the shear stress field. The area where floodplain excavation is proposed will become seasonally wetter and be inundated with flow from the River Vyrnwy during winter.
- A land drain crossing the site will be severed which will provide an opportunity to input additional minor flow into the backwater features and increase surface wetness of the adjacent floodplain.
- The options proposed work with the principles of floodplain reconnection, valley floor wetting, river and floodplain naturalisation, and habitat and feature improvements.
- A services search has been undertaken by the client for the River Vyrnwy and surrounding site area, no main infrastructure utilities were found crossing the site which would impact the design. There are utilities following the local road networks which contractors should be aware of if tracking over with heavy machinery. Dynamic Rivers accept no liability or responsibility for any services present or impacted as a result of any works undertaken on site.
- A services search should be undertaken prior to works commencing 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, with appropriate liaison with the service provider. 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 undertake a C.A.T4 / radio-detection scan, in liaison with the provider, and locate these services prior to excavation commencing if deemed required.
- Baseline bed shear stress model outputs show that generally under extreme flows values range between 20-80 N/m$^2$ within the River Vyrnwy channel study reach, with higher shear stresses through the reach upstream from the site where the channel is narrower and straighter. Across the floodplain, shear stresses reach around 20-30 N/m$^2$ but are generally much lower. Within the feature locations shear stress is typically <10N/m$^2$ under baseline conditions and there are negligible changes with the restoration features considered. There is a very minor increase to shear stress in-channel local to the connection of the southern backwater feature for the 1 in 100yr plus climate change event or the low order 2yr flood event, due to the significant wetted area under baseline conditions. This increase occurs on the falling limb of the hydrograph as ponded flows recede, the increase is only 10-20N/m$^2$ over 30-40N/m$^2$ at the location and remain well within typical values for the overall reach, however this is likely to locally influence patterns of erosion and deposition within the channel as part of natural process over time.
- Most cohesive soils, especially when vegetated, resist over 100 N/m$^2$ and outputs show that we are within this range (less than 10 N/m$^2$) generally for both lower and higher order flows across the floodplain. However, flow concentration will still instigate low level headcutting as part of natural processes associated with floodplain reconnection, chute channels, palaeo extension features and associated development. Gravels/cobbles and fine sediments are likely to deposit within the channel (as they do currently) at a slightly greater rate due to the improved floodplain connectivity, and across reconnected backwaters more readily. At the point downstream from the large backwater deposition may occur at a slightly reduced rate due to the minor increase in shear stress. This is part of natural processes and is encouraged as part of the scheme. The backwaters created are low energy features and may be subject to some infilling over time, again this is a natural process for features of this type and is part of the evolution of the floodplain area. These features will be

seasonally wet, although may retain water all year round dependent on rainfall and any flow from the ditch to the west of the site. Natural processes and associated erosion and deposition may change the flood regime and pattern over time. This should be continued to be monitored as part of a monitoring programme following construction.

- Modelling shows a minor and localised reduction near to the site for the 1 in 2yr flood extent compared with baseline. There is no perceptible change for the 1 in 20 and 1 in 100yrCC events due to the significant flooded area of the River Vyrnwy floodplain under baseline and proposed design conditions.
- Modelling has shown that for the updated Option 5 Revision 1, during typical summer flow (Q95) there is approximately 1ha of flow ponded to at least 250mm depth within the backwater features, this increases to 2.6ha during typical winter flow (Q10). There is therefore 1 to 2.6ha of seasonally variable habitat available for *L. natans* resulting from the November 2024 updated final design.
- Dynamic Rivers have undertaken a predicted wet floodplain habitat assessment into areas of floodplain which could potentially develop into functional wet grassland, fen/mire or other wetland type habitat using the floodplain wetting tolerance ranges suggested by Wheeler et al. (2004). Due to the disconnection of summer flows within the River Vyrnwy from the floodplain at the site, it is unlikely that a diverse mix of valley floor wetland habitat will develop, due to the over-dry floodplain. The tool did indicate that the margins of the backwater could potentially develop into swamp type habitat. L. natans may succeed within the initial stages of swamp habitat development, but there is a risk of out-competition by other swamp preferential species as part of natural biotic processes and it is unlikely to survive due to succession without intervention (management).
- Dependent on flow volumes, topography and water levels, it could take a considerable amount of time for reconnected/created features and the floodplain to become wet following completion of the works. This is an unknown and the risk cannot be removed as part of the design process. Features and the floodplain could be drier than anticipated.
- Unknown and hidden drainage could impact the functioning of reconnected areas and created features. This is an unknown and the risk cannot be removed as part of the design process. Features and the floodplain could be drier than anticipated.
- Any excess spoil will need to be spread elsewhere out of active flood zone areas or removed from site. When spreading material and tracking over any archaeologically sensitive areas (where applicable), this should be undertaken using Low Ground Pressure Plant. An archaeological watching brief may be required.
- The flooding regime could change over time as the river and floodplain naturalises and responds to the proposed works. This is part of natural processes. Proposed spreading areas should be outside of the NRW and modelled flood zones. Any excess spoil will need to be spread elsewhere out of active flood zone areas or removed from site. There will be a period of time where works are partly complete. If a flood were to occur at this point during the construction, then unpredicted flooding could occur. This risk cannot be removed as part of the design process.

### 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.

- A services search has been undertaken by the client for the River Vyrnwy and surrounding site area, no main infrastructure utilities were found crossing the site which would impact the design. There are utilities following the local road networks which contractors should be aware of if tracking over with heavy machinery. Dynamic Rivers accept no liability or responsibility for any services present or impacted as a result of any works undertaken on site.
- 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.
- It is recommended that the client considered future hydrological management of the Montgomery Canal so that the sluice discharging flows to the western ditch can be opened wider and/or more frequently. Any additional flows from the canal sluice will be discharged via the chute channels and into the backwater features providing additional flow availability benefit.

# 1. Appendix A

On the Powys land to the east of the Vyrnwy site, the main stream the Nant Melin discharges directly to the River Vyrnwy as does a small tributary to the eastern extent of the site (Figure A.1). Both of these watercourses could be exploited to provide a source of flow to this site which has a paleochannel feature running through it at a lower elevation to the surrounding valley floor. The presence of a pond feature to the east of this area suggests an elevated water table at the site, making it a potentially ideal location for wetland development.


**Figure A.1 – Powys land existing hydrological function**

There is an existing paleochannel feature on site, the base of this feature is typically 1m below adjacent ground levels. The modified condition of the Nant Melin and small tributary to the east to improve flow conveyance away from the site are preventing the paleochannel area from wetting up.

There is potential to create a wetland habitat template on site which is not dependent on the water level within the River Vyrnwy (Figure A.2), by raising the bed levels of the two modified tributaries on site.

The area indicated as paleochannel excavation approximates to around 0.9ha. This could be less than 1m deep cut as providing variance in levels across the feature is preferential.

Topographic data suggests the presence of an abandoned alluvial fan from the valley side tributary the Nant Melin, this feature could be reactivated and incorporated into the design of the site to split flows naturally between the two paleochannel locations meanwhile restoring the historic river feature.

The potential area of wetland indicated is the assumed passive response to the restoration, this area is situated below the adjacent valley floor levels and will become permanently wetter. Depending on specific ground levels there may be pockets of open water here or wet marginal ground.

A kested hedge is proposed at the upstream extent of the paleochannel feature to prevent flows backing up onto the Vyrnwy site. However, could part of this site be included within the overall land purchase then the paleochannel feature which extends onto the Vrynwy site could also be included to increase the extent of restored feature. Additional kested hedges could be constructed from cohesive arisings to manage flows from spilling to third party land as required.

*L. natans* should be able to occupy this new wetland habitat and, if required localised deeper excavations within the features could be created to ensure deeper ponded sections of open water. Other species may still outcompete the *L. natans* as part of natural succession which is an unavoidable natural process.

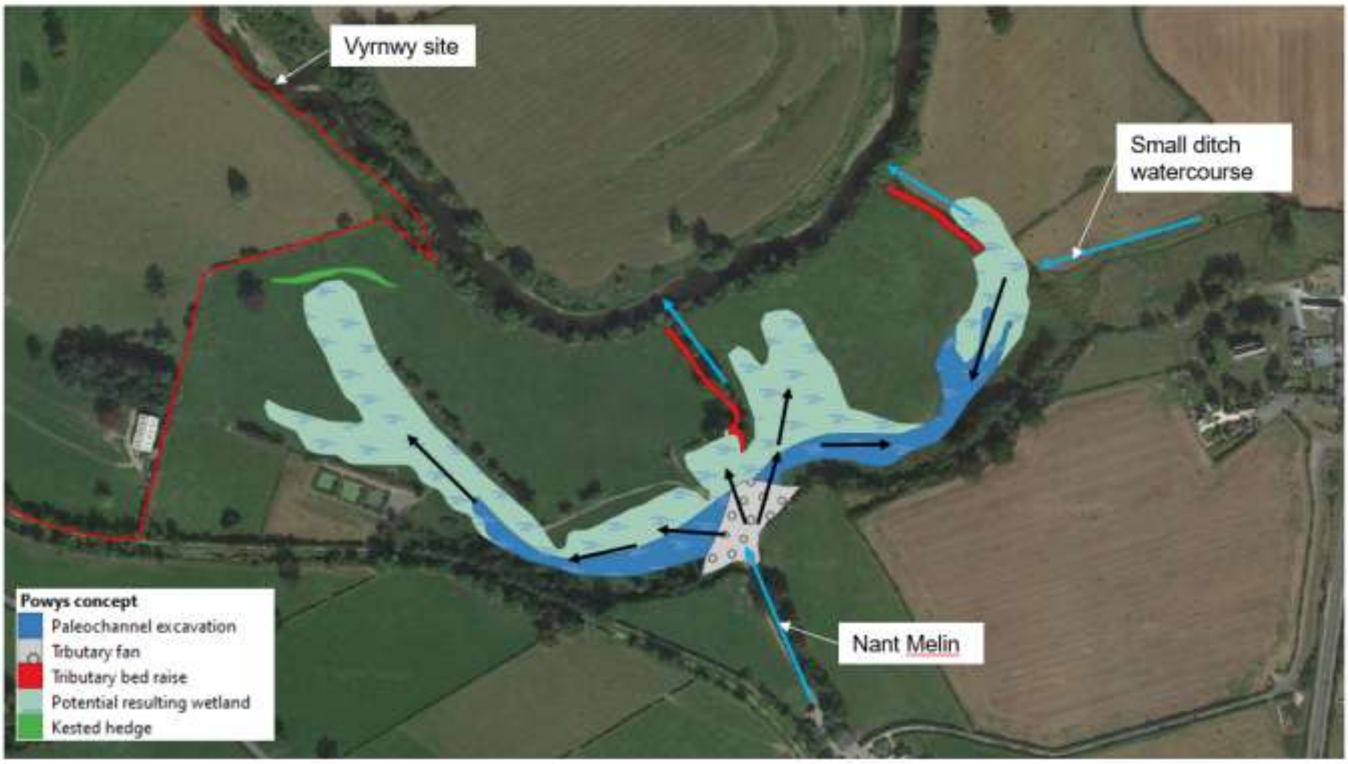



**Figure A.2 – Powys land change to hydrological function with proposed restoration works. Black arrows are potential hydrological function post-restoration.**

# 2. Appendix B

# Flood estimation – calculation record

## Site/project name:

## Date:

### Introduction

This document is a supporting document to the Natural Resources Wales Flood Estimation Technical Guidance Note V3. It provides a template for recording calculations and decisions made during flood estimation. It will often be complemented by more general hydrological information given in a project report. The information given here should be enough to enable the work to be reproduced in the future.

Note 1: Table, content or page layout can be adapted to best present relevant information. Additional rows should be added to, or removed from tables as appropriate.

Note 2: Probability of flood occurrence is traditionally expressed within Hydrology as a Return Period, this is the average time between years with at least one larger flood. It can also be expressed as Annual Exceedance Probability (AEP), and this is often more appropriate to use when communicating with non-hydrologists. Return Period has been retained within this document but can be replaced with AEP if wished.

### Contents

## Approval

| | Name | Qualifications | Date | Competence level |
|---|---|---|---|---|
| **Calculations prepared by:** | *Rory Clements* | BSc (Hons)<br><br>CGeog (Geomorph) | 01/02/2025 | Senior Hydrologist |
| **Calculations checked by:** | Rob Williams | PhD | 02/02/2025 | Senior Hydrologist |
| **Calculations approved by:** | Seb Bentley | BSc Msc | 03/02/2025 | Principal Hydrologist |
| Competence levels:<br><br>level 1 – hydrologist with minimum approved experience in flood estimation<br><br>level 2 – senior hydrologist<br><br>level 3 – senior hydrologist with extensive experience of flood estimation | | | | |

## Abbreviations

| | |
|---|---|
| AEP | Annual exceedance probability |
| AMAX | Annual maximum flow |
| AREA | Catchment area ($km^2$) |
| BFI | Base flow index |
| BFIHOST | Base flow index derived using the HOST soil classification |
| BFIHOST19 | Base flow index derived using the revised (2019) HOST soil classification |
| DPLBAR | Mean drainage path length (km) |
| DPSBAR | Mean drainage path slope (m/km) |
| FARL | FEH index of flood attenuation due to reservoirs and lakes |
| FEH | Flood Estimation Handbook |
| FPEXT | Floodplain extent |

| | |
|---|---|
| HOST | Hydrology of soil types soil classification |
| NRFA | National river flow archive |
| POT | Peaks over a threshold |
| QMED | Median annual maximum flow (with Annual Exceedance Probability of 50% / return period 2 years) |
| ReFH | Revitalised flood hydrograph method – used for rainfall runoff method |
| SAAR | Standard average annual rainfall (mm) |
| SPR | Standard percentage run-off |
| Tp | Time to peak |
| URBEXT2000 | Index of urban extent in the year 2000 |
| WINFAP | Windows Frequency Analysis Package – can be used for FEH statistical peak flow method |

# 1. Method statement

## 1.1 Overview of requirements for flood estimates

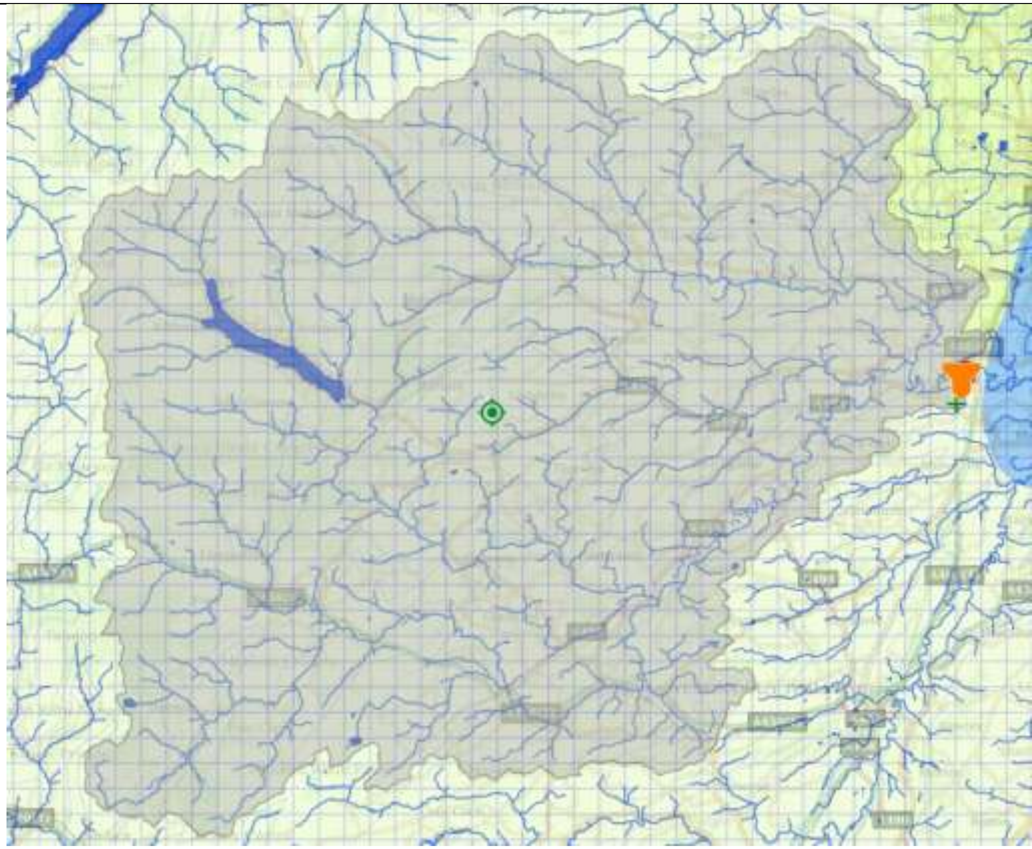
| Item | Comments |
|---|---|
| Give an overview which includes:<br>• purpose of study<br>• names of river/s<br>• location<br>• number of calculation points and if peak flows or hydrographs are required<br>• previous relevant calculations<br>• availability of flood history | The purpose of this flood estimation calculation is to provide a single inflow (one calculation point) for a hydraulic model of the River Vyrnwy at Llanymynech. The hydraulic model will assess the impact of a proposed river restoration scheme on fluvial flood risk.<br><br>Flood risk review is being undertaken for completeness in support of design development, the river restoration proposal results in a net removal of material from active flood zones and is not considered to pose a flood risk or be at flood risk from the River Vyrnwy.<br><br>Peak flows and hydrographs are required. WINFAP-FEH 5 (v5.2.9) and ReFH 2.3 (v3.3.8) have been utilised for this works.<br><br>The site and adjacent flood plain is at known flood risk, with numerous press and video (youtube records) online from the previous 5 years. The River Vyrnwy floodplain at the site is predominantly rural and receptors are typically agricultural land with pockets of habitation within local villages. |

## 1.2 Overview of catchment

| Item | Comments |
|---|---|
| Brief description of catchment, including key features needing consideration or | The River Vyrnwy catchment at the site is a predominantly rural catchment, the catchment is relatively large at 783.5km$^{2}$. The large catchment area provides confidence in the FEH |

| Item | Comments |
| --- | --- |
| reference to section in accompanying report.<br><br>Map/s should be presented here or in section 2.1 of this report. | boundary and it is not necessary to check and update the boundary using a GIS watershed analysis (Figure 1).<br><br>The Llanymynech gauging station is situated immediately upstream from the site location and provides the best opportunity for donor site and leading pooling group stations within the FEH-web service.<br><br>There is one large reservoir within the catchment namely the Lake Vyrnwy, however, the lake only impounds approximately 10% of the catchment area and is not considered to have a major attenuating influence on flood flow at the site, this is illustrated by a FARL value of 0.97.<br><br>The catchment is underlain by superficial deposts of unsorted glacial till, mixed permeability alluvium and river sand and glacial sand and gravel. Underlying the superficial deposits are multiple bedrock formations typically comprising impermeable mudstone, sandstone and siltstone[1]. The superficial geology is considered low productivity aquifers (Figure 1) and is considered only moderately permeable, as such has a moderate BFIHOST19 value of 0.41.<br><br>The catchment incorporates both headwaters and piedmont zones and is therefore relatively steep with an average catchment slope (DPSBAR) of 160.9m/km.<br><br>A moderately high SAAR value of 1335m indicates substantial annual rainfall occurs within the River Vyrnwy catchment. |

[1] Geology mapping has been reviewed on the British Geological Survey Geoindex using 1:625,000 scale mapping due to the large catchment size https://mapapps2.bgs.ac.uk/geoindex/home.html

| Item | Comments |
| --- | --- |
| | <br><br>Figure 1. River Vyrnwy catchment at the site. Drainage network and large lake/reservoir waterbodies shown. Catchment screenshot from the FEH web service. BGS aquifer productivity mapping underlays showing low productivity.<br><br>The online search for flood records found local press and YouTube entries for several large flood events within the last 5 years (date of search 29/01/2025), these occurred between |

| Item | Comments |
|---|---|
| | December and February and are indicative that fluvial flooding tends to be seasonally (winter) driven. |

## 1.3 Source of flood peak data

| Item | Comments |
|---|---|
| Was the NRFA Peak Flows dataset used? If so, which version? | Version 13, released August 2024. This contains data up to water year 2022-23 at most sites. |

## 1.4 Gauging stations (flow or level)

Within, or near to, the study area. Most stations will be included on National River Flow Archive (NRFA), but other stations may also be available.

| Watercourse | Station name | NRFA number | Grid reference | Catchment area ($km^2$) | Location relative to study area (eg, within), note any significant differences in catchments (eg URBEXT) |
|---|---|---|---|---|---|
| River Vyrnwy | Llanymynech | 54028 | SJ252196 | 778 | Immediately upstream from site location and useful for donor and pooling<br><br>Long term AMAX dataset to 1969 |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |

## 1.5 Data available at each gauging station

| Station name or number | Start and end date on NRFA | Suitability (Pooling/ QMED/ Neither)? | Update for this study? | Comments on data availability (quality is covered in next section). If not a QMED or pooling station then describe how data will be used e.g. for Tp calculation or QMED calculation from daily mean flow |
|---|---|---|---|---|
| 54028 | 1969-present | Both | No | A review of hydrograph shape from ReFH2 will be undertaken against observed events for the 2024 year (latest available online). |
| | | | | |
| | | | | |

## 1.6 Data quality at each gauging station

| Station name or number | Comments on rating quality focusing on QMED and above<br><br>e.g. degree of extrapolation, availability of recent flow gaugings, amount of scatter in the gaugings, bank full level and out of bank flow |
|---|---|

<table>
<tr><td>54028</td><td>The flow is gauged beyond QMED and rating above bankfull has been confirmed with gauging’s (NRFA website 2025). There is some degree of scatter in the gauging’s used for rating determination but generally they are in good agreement and there is confidence in the rating (Figure 2)

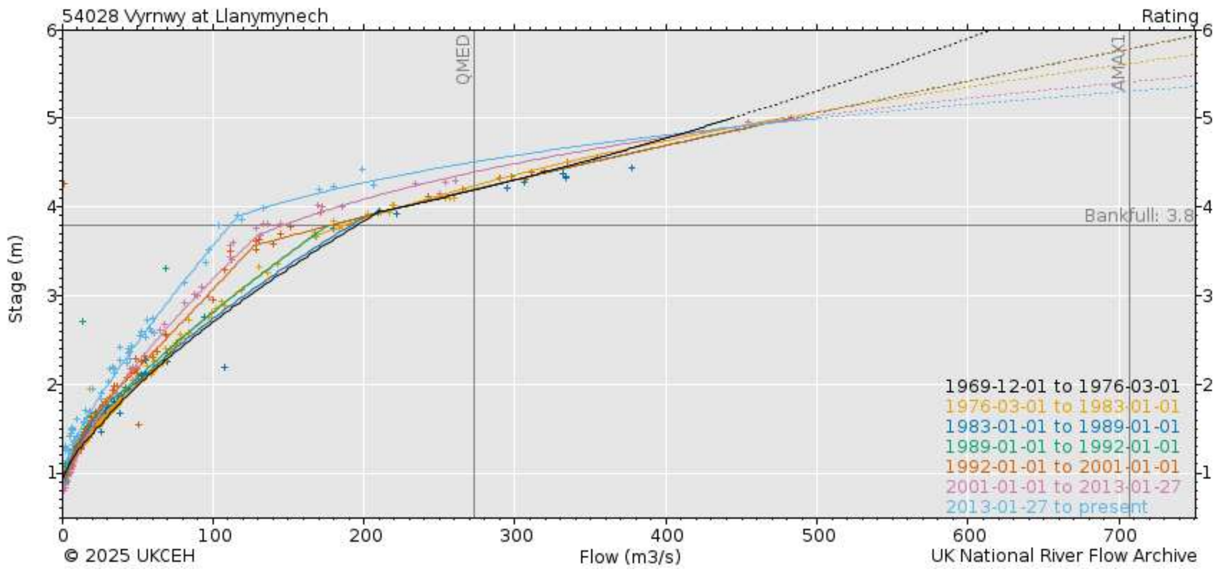



Figure 2. NRFA rating information for the Llanymynech gauging staiton</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
</table>

## 1.7 Other data available and how it has been obtained

Consider flood history and local data if available.

| Type of data | Source of data | Details and reference/link to relevant reports |
|---|---|---|
| Historic flood data | Online searches | Some examples are linked above, a google search identifies historic entries of flooding near Llanymynech and the A483 downstream from the site.<br><br>Drone footage on Youtube shows the wider area around the site to be flooded several tuimes within the last few years https://www.youtube.com/results?search_query=flooding+llanymynech<br><br>The NRW flood alert for the River Vyrnwy at Llanymynech is frequently activated during winter https://flood-warning.naturalresources.wales/Detail/101FWFWN253<br><br>The NRW flood alert for the wider River Vrnwy catchment is frequently activated during winter https://flood-warning.naturalresources.wales/Detail/101WAFVY10 |
| 15-min river level/flow and rainfall data for events (if carrying out Tp or ReFH analysis) | NRW data website used to download 15 minute level data for Vyrnwy gauge | Three events occurring during 2024 have been investigated to inform hydrograph shape compared with the default ReFH2 design hydrograph. Time to peak and duration have been adjusted. The events selected are not the largest events for 2024, but are isolated events so comparable with design hydrograph methods. All larger events indicated at least two separate flood peaks within the hydrograph and have been discounted for in this context. |
| Results from previous studies | None known | |

## 1.8 Initial choice of approach

| Item | Comment |
|---|---|
| **Outline the conceptual model.** Address questions such as:<br>• Where are the main sites of interest?<br>• What is likely to cause flooding at those locations? (e.g. peak flows, flood volumes, combination of peaks, groundwater, snowmelt, tides)<br>• Might those locations flood from runoff generated on part of the catchment only e.g. downstream of a reservoir? | The main site of interest is a river restoration site downstream from the Llanymynech bridge, it is part of the wider Montgomery Canal restoration.<br><br>The main driver of flooding at the site is fluvial flooding, the site is understood to experience semi-regular fluvial flooding alongside the majority of the River Vyrnwy catchment. The site is a functional river restoration and ultimately will create slightly more storage for flood waters locally. Flood peak and hydrograph volume are responsible for flooding at the site, other sources of water e.g. groundwater or surface water are limited. |
| **Any unusual catchment features to account for?** For example:<br>• highly permeable (BFIHOST> 0.65)<br>• highly urbanised – consider choice of method carefully; consider aritifical drainage and storm sewer inflow and outflows<br>• small catchment (<40 $km^2$) – small catchment pooling method<br>• pumped watercourse – consider lowland catchment version of rainfall-runoff method<br>• major reservoir influence – consider flood routing<br>• extensive floodplain storage – consider choice of method carefully | This is a large catchment, with the catchment are to the gauge at Llanymynech account for over 99% of the total site catchment area.<br><br>The catchment is moderately impermeable, slightly influenced by a reservoir which impounds approximately 10% of the catchment and moderately steep.<br><br>The site is predominantly rural URBEXT2000 is zero.<br><br>All descriptors are considered representative and within normal ranges for ReFH2 and FEH statistical. |

| Item | Comment |
| --- | --- |
| **Initial choice of method(s) and reasons**<br><br>• Will method often known as FEH Hybrid be used for peak flow estiamtes? (Statisical for QMED to 1% AEP, then growth factor from ReFH applied to 1% event for events to 0.1% AEP)<br>• If not appropriate, describe why and give details of the other method/s to be used.<br>• What method will be used for hydrograph calculation?<br>• Will the catchment be split into sub-catchments/intervening areas? If so, how will flows for intervening areas be estimated? | FEH hybrid will be applied.<br><br>ReFH2 will be utilised for hydrograph calculation, a review of duration and time to peak will be undertaken.<br><br>Flows are calculated for one upstream inflow only as a lumped inflow. |
| Software to be used including version number | WINFAP FEH 5 (v5.2.9) and ReFH2.3 (v3.3.8) |

# 2. Locations where flood estimates are required

## 2.1 Map of study area, including subject site(s) and gauging stations (where applicable).


Figure 3. Site location shown with orange marker. Llanymynech gauging station and metadata shown inset. From FEH Web Service 2025.

## 2.2 Summary of subject sites

The table below lists the locations of subject sites. Use site codes in all subsequent tables to save space.

| Site code | Watercourse | Site Name (description) | Easting | Northing | AREA on FEH Web Service ($km^2$) | Revised AREA if altered ($km^2$) | Peak flow, hydrograph or both required? |
|---|---|---|---|---|---|---|---|
| 001 | River Vyrnwy | Vyrnwy at Llanymynech | 326400 | 319400 | 783.5 | 783.5 | Both |
| | | | | | | | |
| | | | | | | | |

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

| Site code | AREA ($km^2$) | BFIHOST19 | DPLBAR (km) | DPSBAR (m/km) | FARL | FPEXT | PROPWET | SAAR (mm) | URBEXT 2000 |
|---|---|---|---|---|---|---|---|---|---|
| 001 | 783.5 | 0.41 | 36.91 | 160.9 | 0.97 | 0.51 | 0.053 | 1335 | 0.0009 |
| | | | | | | | | | |
| | | | | | | | | | |

## 2.4 Checking catchment descriptors

| Item | Comment |
|---|---|
| Record how catchment boundary was checked<br>• Describe any changes<br>• Add maps if needed | The catchment boundary is large so less likely to be erroneous. It has been visually checked against OS mapping and OS terrain data and is found to be representative. |
| Record how catchment descriptors were checked, especially soils<br>• Describe any changes<br>• Include a before and after table if necessary | The catchment BFIHOST19 value of 0.41 has been visually checked against BGS Geoindex Geology mapping and Landis Soilscapes mapping. The catchment has parcels of freely draining soils within the lower reaches, blanket bog in the upper reaches and impeded draining in the upper to mid reaches. The superficial geology underlying the catchment is mixed permeability glacial and alluvial material, with impermeable mudstone, sandstone and siltstone underlying the superficial deposits. Generally these descriptions are compatible with a moderately permeable BFIHOST value. |

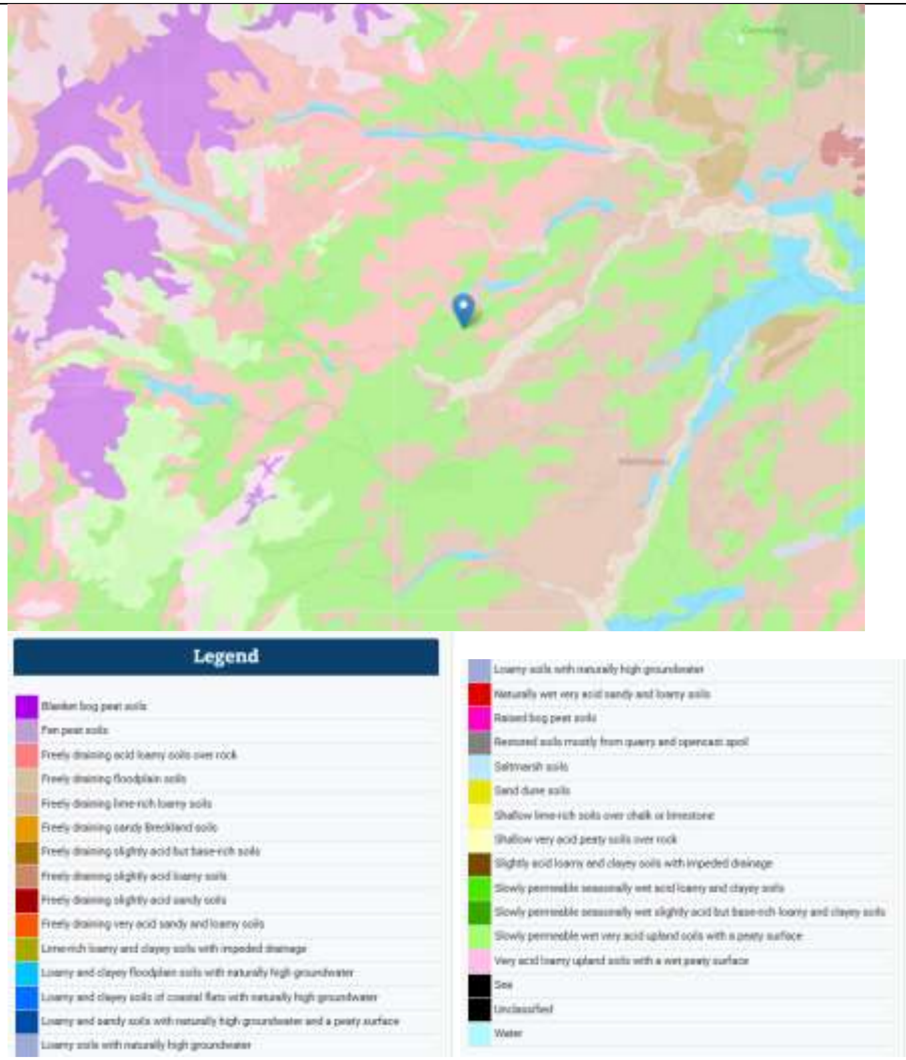



Figure 4. Landis Soilscapes mapping and descriptions for the Vyrnwy catchment.

| | |
|---|---|
| Method for updating URBEXT<br>• Refer to WINFAP Urban Adjustment procedures/guidance | Catchment is predominantly rural with no major developing warranting an update of URBEXT2000. Urban adjustment has been applied with no changes to flows. |

# 3. Statistical method

## 3.1 Donor stations and QMED adjustment factors

Note that donor catchments will usually be rural but may be urban provided the data is deurbanised prior to the adjustment process. Include a map if necessary.

| Station name | NRFA station number | Record Length | Is station hydrologically connected to subject site? Ie, upstream / downstream | Gauged QMED ($m^3/s$) | Deurbanised Gauged QMED (A) ($m^3/s$) | Catchment descriptors QMEDrural (B) ($m^3/s$) | Adjustment ratio (A/B) | Chosen or rejected |
|---|---|---|---|---|---|---|---|---|
| (Vyrnwy @ Llanymynech) | 54028 | 45 | Almost immediately upstream from site | 264.248 | 264.011 | 315.134 | 0.84 | Chosen |
| (Tanat @ Llanyblodwel) | 54038 | 48 | A tributary of the Vyrnwy | 79.320 | 79.247 | 114.253 | 0.69 | Chosen |
| (Severn @ Montford) | 54005 | 69 | Downstream significantly | 307.379 | 306.027 | 532.007 | 0.58 | Chosen |
| (Hirnant @ Plas Rhiwedog) | 67013 | 12 | | 24.081 | 24.081 | 37.842 | 0.64 | Chosen |
| (Ceiriog @ Brynkinalt Weir) | 67005 | 24 | | 30.000 | 29.962 | 58.390 | 0.51 | Chosen |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| (Dee @ Manley Hall) | 67015 | 51 | | 227.000 | 226.045 | 365.080 | 0.62 | Chosen |

**Comments**

- Mention; distance from subject site (based on catchment centroid), whether they are on the same, adjacent or nearby watercourse and
- features which may impact applicability, eg FARL , quality of flood peak data, length of record.

All sites have comparable FARL, 67015 is slightly lower at 0.93 but last in the group and other descriptors match very well so all have been retained within the group. All donor sites are relatively close to the Vyrnwy Catchment within the catchment area context and all sites have good data records.

Adjustment for catchment descriptors against QMED gauged agrees well at all donor sites, with a reduction indicating that QMEDcds is overestimating flow.

## 3.2 Overview of estimation of QMED at each subject site

- Methods: CD: catchment descriptors alone, DT: data transfer, BCW: catchment descriptors and bankfull channel width, FV: flow variability (using flow duration statistics)
- Urban adjustment procedures should be applied regardless of whether the subject site is rural or urban.
- If more than one donor has been used, use multiple rows for the site and give the weights used in the averaging. Record the weighted average adjustment factor in the table.
- Edit table columns/add rows as needed

| Site code | QMEDrural from CDs ($m^3/s$) | Method | NRFA numbers for donor site/s used | Distance between centroids (km) | Distance attenuation alpha factor used? If not explain why below. | Weighting of donor station for QMED adjustment if amended from default | Final adjustment factor applied to site QMED (calculate from QMEDs if WinFap used) | Final estimate of QMEDrural ($m^3/s$) | Final estimate of QMEDurban ($m^3/s$) |
|---|---|---|---|---|---|---|---|---|---|
| 001 | 261.861 | Donor | 54028<br>54038<br>54005<br>67013<br>67005<br>67015 | 0.10<br>9.82<br>12.13<br>17.14<br>19.93<br>21.88 | Yes as default | Retained as default | 0.83 | 261.63 | 261.86 |
| | | | | | | | | | |
| | | | | | | | | | |
| **Distance attenuation alpha factor comments** | | | | | | | | | |

| | |
|---|---|
| **Are the values of Final QMED and QMED adjustment factors consistent, for example at successive points along the watercourse and at confluences?** | There is only one site location estimated however, the trend in donor sites adjustment supports the value and the final adjustment value is similar to that at the Llanymynech gauging station immediately upstream. |

## 3.3 Derivation of pooling groups

- Several subject sites may use the same pooling group.
- The composition of pooling groups should be presented in the Appendix.

| **Pooling group name** | **Site for which pooling group was derived** | **If applied to more than on site, list their codes** | **Method: Single Site / with History, Enhanced Single Site or Pooled / Small Catchment Pooled?**<br><br>Include reasons for choice of method | **Changes made to default pooling group, with reasons**<br><br>Include any sites that were investigated but retained in the group |
|---|---|---|---|---|
| P001 | 001 | | Pooled | The default pooling group has been reviewed but not adjusted. |
| | | | | |
| | | | | |
| **Were non-flood year adjustments made to any stations? if so give details** | | | Only two stations have non flood years, totally three non flood years. These were the lowest ranking two stations within the group and therefore have minimal influence on derived growth curves, no changes have been made. | |

| | |
|---|---|
| **URBEXT2000 threshold used to create pooling group(s).** | *We recommend that this is set to 0.3 to make maximum use of available data and that growth curves are deurbanised appropriately* |
| **Have pooling group growth curves been deurbanised?** | All stations within the group have URBEXT2000 values of 0.006 or lower, essentially no urban influence. Deurbanised growth curves were investigated but not selected as no change in predicted growth curves occurred compared with rural estimates. |

## 3.4 Derivation of flood growth curves at subject sites

- A pooling group derived at one location can be applied to estimate growth curves at several ungauged sites. However, each site may have a different urban adjustment, and therefore different growth curve parameters.
- Urban adjustments to growth curves should use the latest methodologies in WINFAP
- Any relevant frequency plots from WINFAP, particularly showing any comparisons between single-site and pooled growth curves (including flood peak data on the plot) should be shown in an Appendix.

| Site code | Pooling group name | Distribution used and reason for choice | Was an urban adjustment made | Growth factor for 100-year return period (1% AEP) event |
|---|---|---|---|---|
| 001 | P001 | Generalised Logistic, FEH recommended for UK catchments | Investigated but shown to make negligible difference to rural estimates | 2.335 |
| | | | | |
| | | | | |

## 3.5 Flood estimates from the statistical method

| Site code | Flood peak ($m^3/s$) for the following return period or AEP events | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **2**<br>**50%** | **5**<br>**20%** | **10**<br>**10%** | **20**<br>**5%** | **30**<br>**3.3%** | **50**<br>**2%** | **75**<br>**1.3%** | **100**<br>**1%** | **200**<br>**0.5%** | **500**<br>**0.2%** | **1000**<br>**0.1%** |
| 001 | 261.6 | 332.0 | 384.7 | 442.5 | 462.7 | 479.9 | 531.5 | 576.5 | 611.0 | 703.4 | 849.8 |
| | | | | | | | | | | | |
| | | | | | | | | | | | |

# 4. Revitalised flood hydrograph (ReFH) method for peak flow estimation

This section records calculations for peak flow estimates and will generally use default parameters. If different calculations are subsequently made for hydrographs, details should be recorded in section 5.

## 4.1 Design events for ReFH method for peak flow estimation

| Site code | Season of design event (summer or winter) | Recommended Storm duration (hours) |
|---|---|---|
| 001 | Winter | 15 |
| | | |
| | | |

| | |
|---|---|
| **Was FEH22 used for design rainfall statistics? If not, why?** | Yes |
| **Comments** | |

## 4.3 Peak flow estimates from the ReFH method

| | | **Flood peak ($m^3/s$) for the following return periods (in years) or AEP** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Site code** | **Urban/ rural?** | **2**<br>**50%** | **5**<br>**20%** | **10**<br>**10%** | **20**<br>**5%** | **30**<br>**3.3%** | **50**<br>**2%** | **75**<br>**1.3%** | **100**<br>**1%** | **200**<br>**0.5%** | **500**<br>**0.2%** | **1000**<br>**0.1%** | **100:1000**<br>**1%:0.1%**<br>**ratio** |
| 001 | Urban | 235.3 | 300.7 | 349.3 | 400.7 | 432.9 | 476.0 | 512.3 | 539.1 | 607.68 | 706.3 | 786.3 | 0.689 |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |

| | |
|---|---|
| How do peak flows compare to statistical estimates. | |

# 5. Revitalised flood hydrograph (ReFH) method for model inflow hydrographs

## 5.1 Parameters for ReFH model for model inflow hydrographs

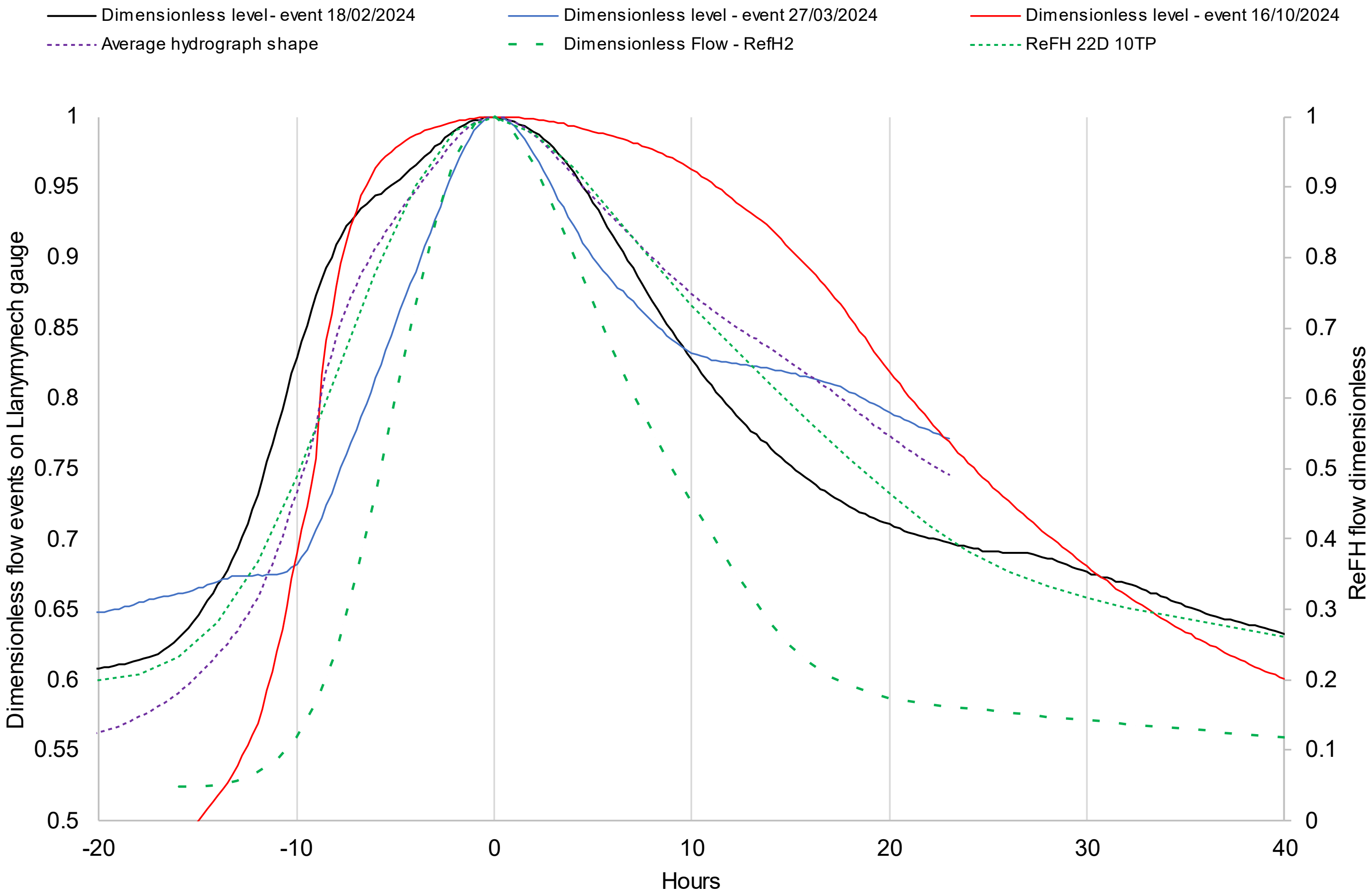
This section records calculations for model inflow hydrographs, parameters may have been calibrated and storm durations changed.

If parameters are all estimated from catchment descriptors, they are easily reproducible, so it is not essential to record them here –Just enter ‘all’ under site code and ‘Catchment descriptors’ under method. Table can be amended as needed.

| Site code | Details of method<br>• Catchment descriptors (CD)<br>• Tp (Time to peak) calculation<br>• Optimisation (Calibration Utility) | CD Tp (hours) | Adjusted Tp if different (hours) |
|---|---|---|---|
| 001 | Catchment descriptors with time to peak and duration reviewed | 6.49 | 10 |
| | | | |
| | | | |
| | | | |

| | | | |
|---|---|---|---|
| | | | |
| **Description of any Tp calculation or calibration work, add references to other documents where appropriate** | Default catchment descriptors estimated a time to peak of 6.49 and a storm duration of 15 hours.<br><br>15- minute level data for the Vyrnwy at Llanymynech is available for the previous 12 months on the NRW data explorer. This data was reviewed, numerous large flow events have occurred within the last 12 months however many of these are caused by two or more storm events coinciding. The three largest events which were driven by one flow event only have been selected for review against ReFH design hydrographs. These events occurred on 18 February, 27 March and 16 October 2024.<br><br>To compare hydrograph shape, the level hydrographs were scaled by the peak of each event and the ReFH hydrograph by the peak flow, making the hydrographs dimensionless. Peaks were aligned to zero hours for comparison of shape, this is similar to the approach for design hydrograph synthesis from gauged data described by Archer et al., 2010[2].<br><br>Reviewing the event hydrographs (Figure 5 below) alongside the default ReFH2 hydrograph from catchment descriptors, it is evident that the recommended ReFH2 hydrograph volume and time to flood peak are likely underestimated. Adjustments were made to the storm duration and time to peak iteratively, as the two are dependent. A value of 10hrs for time to peak and associated 22hrs for storm duration result in a hydrograph synthesis which matches very well with the average hydrograph shape in Figure 5. FEH-statistical and adjusted 1000yr estimate will be adopted for design flows so the influence on predicted peak flow due to adjustments is not considered to impact the assessment. | | |

[2] Archer, D., Foster, M., Faulkner, D. and Mawdsley, J., 2000, October. The synthesis of design flood hydrographs. In *Proc. ICE/CIWEM Conf. Flooding–Risks and Reactions. Terrace Dalton, London*.

| | Figure   Figure 5. Comparison of observed hydrograph shapes (solid lines), average dimensionless hydrograph are purple dotted line, default RefH2 hydrograph in dot-dash green and adjusted Tp and duration RefH2 hydrograph in dotted green line. |
|---|---|

## 5.2 Design events for ReFH method for model inflow hydrographs

| **Storm duration (hours)** | **ARF** | **Source of Storm Duration and ARF** | **Why Chosen** |
|---|---|---|---|
| 22 | 0.87 | ARF calculated based on time to peak and duration adjustments | Details above on time to peak and duration review due to gauged hydrograph shape at the Llanymynech gauge near to the site. |
| | | | |
| | | | |
| | | | |
| | | | |
| **Were hydrographs scaled to alternative peak flow estimates? If so, give details** | | | Yes, FEH-statistical will be adopted as there is a good degree of confidence in the estimates due to location of the Llanymynech gauge upstream from the site. |
| **Provide link/reference to location of hydrographs or provide in appendix** | | | **Design hydrographs are provided below** |

# 6. Final peak flow and hydrograph estimates

## 6.1 Comparison of peak flow estimates from different methods

This table compares peak flows from the ReFH method, FEH Statistical method and any available previous study at each site for two key return periods. Note and explain any significant difference from previous studies.

| | QMED (50% AEP) | | | | 100-year return period / 1% AEP | | | |
|---|---|---|---|---|---|---|---|---|
| **Site code** | **Statistical** | **ReFH** | **Previous Study** | **Comment** | **Statistical** | **ReFH** | **Previous Study** | **Comment** |
| 001 | 261.6 | 265.3 | N/a | Statistical is higher and agrees with gauging's at Llanymynech | 611.0 | 539.1 | N/a | Higher statistical estimate agrees with long-term flood record at Llanymynech although data record only 54 years. |
| | | | | | | | | |
| | | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| | | | | | | | | |

## 6.2 Final peak flow estimates

| | **Flood peak ($m^3/s$) for the following return periods (in years) or AEP** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Site code** | **2**<br>**50%** | **5**<br>**20%** | **10**<br>**10%** | **20**<br>**5%** | **30**<br>**3.3%** | **50**<br>**2%** | **75**<br>**1.3%** | **100**<br>**1%** | **200**<br>**0.5%** | **500**<br>**0.2%** | **1000**<br>**0.1%** | |
| 001 | **235.3** | 300.7 | 349.3 | **400.7** | 432.9 | 476.0 | 512.3 | **539.1** | 607.7 | 706.3 | **891.1** | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| **State choice of method, ie**<br><br>Hybrid approach (Statistical for QMED to 100 year, ReFH growth factor from 100yr applied to statistical 100yr, for rarer events) | | | | The FEH statistical method with ratio adjusted (RefH 100/1000 * FEH-stat 100) 1000yr has been adopted as FEH statistical provides a greater degree of confidence in peak flow estimates at this site and the estimates up to 50yrs agree very well with the Llanymynech gauge AMAX immediately upstream. | | | | | | | | |

| | |
|---|---|
| Statistical<br>ReFH | |

## 6.3 Uncertainty

**Give what information you can on uncertainty in the flood estimates**

For example, using the methods detailed in ‘Making better use of local and historic data, and estimating uncertainty in FEH design flood estimation (FEH Local) SC130009

| **Site Code** | **95% confidence interval factor for QMED** (eg 0.48-2.1 for ungauged locations with 0 donors) | **95% confidence interval factor for 100 year (1% AEP) flood** | **Comments,** include comments on QMED estimation method, gauging station relative location/s, record length, data quality, consistency between stations, flood history and catchment characteristics |
|---|---|---|---|
| 001 | 132.3 to 517.5 | 300.7 to 1241.5 | FSE has been estimated using the 6 donor equation on page 6 of Uncertainty in FEH Methods[3]. The resulting FSE value for Qmed is 1.406 and 1.425 for the 100yr flood. |

## 6.4 Hydrographs for modelling

| | |
|---|---|
| **How were these calculated, for example, scaling ReFH hydrographs to final flow estimates, adjusting $C_{ini}$?** include link/reference to hydrographs. | Hydrograph shape generated by RefH catchment descriptors, with adjusted Tp and storm duration. Scaled to FEH statistical flow estimates. |

[3] https://www.hydrosolutions.co.uk/app/uploads/2021/11/Uncertainty-in-FEH-methods-v1.1.pdf

| | |
|---|---|
| **How will flows be applied in the model.** If intervening areas are used, will hydrographs be adjusted to better match downstream flows, or will best estimate inflows be used and resulting downstream flows accepted? | The hydrographs will be applied as a lumped inflow at the upstream extent of a hydraulic model, due to the relatively small site extent only a single inflow location is specified. |

## 6.5 Checks

| | |
|---|---|
| **Are the results consistent, for example at confluences?** | QMED agrees with the gauged flow at the Llanymynech gauge slightly upstream. |
| **What do the results imply regarding the return periods of floods during the period of record?** | Estimates up to the 50yr return period are comparable with the AMAX record at the Vyrnwy at Llanymynech gauging station providing confidence in estimates up to this event. Beyond this it is not possible to compare as the station only has a 54yr data record. |
| **What is the 100-year growth factor? Is this realistic?**<br><br>(The guidance suggests a typical range of 2.1 - 4.0) | 2.335, within typical range |
| **If 1000-year flows have been derived, what is the range of ratios for the 1000-year flow over 100-year flow?** | The 0.1% / 1% AEP event ratio for the methods is:<br><br>FEH Statistical – 1.47<br><br>ReFH2 – 1.65 |

| | |
|---|---|
| **What is the range of specific runoffs (l/s/ha)? Are there any inconsistencies?** | 2yr - 0.3l/s/ha<br><br>100yr - 0.78l/s/ha<br><br>The ranges are comparable with plot scale greenfield runoff estimates for rural catchments, the estimates are on the slightly lower side which is likely due to some permeability within the lower reaches of the catchment and slacker gradient reducing runoff intensity. |
| **How did the results compare with those of other studies?**<br><br>Explain any differences and conclude which results should be preferred | None known |
| **Are the results compatible with the longer-term flood history?** | The results compare well with the Llanymynech gauge up to a 50yr return period, records of flooding in the area in recent years suggest the results correlate well. |
| **Describe any other checks on the results** | The trends explorer for Llanymynech was reviewed, the trends explorer suggests a climatically driven positive trend in flow at the Llanymynech gauge, however consultation with NRW (Demcember 2024 and January 2025) suggested there is not enough confidence to rely on this for flow estimation. The consultation and responses are attached below. |

## 6.6 Assumptions and limitations

| | |
|---|---|
| **List the main assumptions made specific to the study** | Flows rely on gauged data from the Llanymynech gauge for improved confidence, however all flows are statistical estimates and will contain a degree of error. Assessing a range of flood |

| | |
|---|---|
| | flows with climate change allowances helps understand uncertainty across the flood hydrograph range. |
| **Discuss any particular limitations**<br><br>For example, applying methods outside the range of catchment types for which they were developed | |
| **Comment on the suitability of the results for future studies**<br><br>For example, at nearby locations or for different purposes | The results from this study are applicable to future work, however, as is recommended if significant time since this assessment or large flood events have occurred on the Vyrnwy the flows should be reviewed. |
| **Give any other comments on the study**<br><br>For example, suggestions for additional work | The work are for comparative purposes for a assessing work which is a net export of material from a flood zone and have been determined for comparative purposes at this site. |

# Appendix: supporting information

Please include details of your pooling group(s)

## Pooling group composition

QMED and pooling group composition are attached as a separate PDF exported from WINFAP.

## Additional supporting information

# UK Design Flood Estimation

## Summary of ESS/Pooled Estimation Analysis using the Flood Estimation Handbook Statistical Method

| | |
|---|---|
| Date of creation: | 07-01-2025 15:07:14 |
| Software: | WINFAP Version: 5.2.9014 (11448) |
| Peak Flow dataset: | Peak Flow Dataset 11.0.0 |
| Supplementary data used: | No |

### Site details

| | |
|---|---|
| Site number: | 2108853198 |
| Site name: | FEH_Catchment_Descriptors_326400_319400_v5_0_1 |
| Site location: | SJ 26400 19400 |
| Easting: | 326400 |
| Northing: | 319400 |
| Catchment area: | 783.47 km² |
| SAAR: | 1335 mm |
| BFIHOST19: | 0.413 |
| FPEXT: | 0.053 |
| FARL: | 0.969 |
| URBEXT2000: | 0.0009 |

### Site data

**At-site data**

At-site data present: No

# UK Design Flood Estimation

## Summary of ESS/Pooled Estimation Analysis using the Flood Estimation Handbook Statistical Method

## Analysis settings

**Urbanisation settings**

| | |
|---|---|
| User defined: | No |
| Urban area: | 1.10 km² |
| PRimp: | 70.00% |
| Impervious Factor: | 0.300 |
| UAF: | 1.00090 |

**Growth curve settings**

| | |
|---|---|
| Distance Measure Method: | Standard |
| Pooling group URBEXT2000 Threshold: | 0.030 |
| Deurbanise Pooling Group L-moments: | Yes |

**QMED settings**

| | |
|---|---|
| Use at-site data: | No |
| Method: | Donor Station(s) |

## Growth curve data and results

**Pooling group AM data**

| Station | Distance | Years of data | QMED AM | L-CV Observed | L-CV Deurbanised | L-SKEW Observed | L-SKEW Deurbanised |
|---|---|---|---|---|---|---|---|
| 54028 (Vyrnwy @ Llanymynech) | 0.013 | 45 | 264.248 | 0.160 | **0.160** | 0.221 | **0.221** |
| 84004 (Clyde @ Sills of Clyde) | 0.215 | 66 | 210.636 | 0.170 | **0.170** | 0.235 | **0.235** |
| 79002 (Nith @ Friars Carse) | 0.225 | 64 | 447.365 | 0.129 | **0.130** | 0.176 | **0.175** |
| 56001 (Usk @ Chainbridge) | 0.248 | 60 | 373.400 | 0.174 | **0.175** | 0.210 | **0.209** |
| 62001 (Teifi @ Glanteifi) | 0.263 | 62 | 213.000 | 0.219 | **0.220** | 0.374 | **0.373** |
| 12003 (Dee @ Polhollick) | 0.300 | 30 | 301.394 | 0.136 | **0.136** | 0.064 | **0.064** |
| 84018 (Clyde @ Tulliford Mill) | 0.334 | 38 | 247.738 | 0.170 | **0.170** | 0.222 | **0.222** |
| 23004 (South Tyne @ Haydon Bridge) | 0.337 | 62 | 452.368 | 0.149 | **0.150** | 0.203 | **0.203** |
| 47001 (Tamar @ Gunnislake) | 0.340 | 65 | 265.128 | 0.179 | **0.180** | 0.245 | **0.244** |
| 21003 (Tweed @ Peebles) | 0.345 | 62 | 180.883 | 0.207 | **0.207** | 0.294 | **0.294** |
| **Total** | | **554** | | | | | |

# UK Design Flood Estimation

## Summary of ESS/Pooled Estimation Analysis using the Flood Estimation Handbook Statistical Method

**Pooling group suitability**

| Station | Suitability for QMED | Suitability for pooling | Years | Non-flood years | Percentage non-flood years | Mann Kendall (MK) | MK significance (%) | Discordancy | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 54028 (Vyrnwy @ Llanymynech) | Yes | Yes | 45 | 0 | 0.00 | | | 0.257 | |
| 84004 (Clyde @ Sills of Clyde) | Yes | Yes | 66 | 0 | 0.00 | | | 0.105 | |
| 79002 (Nith @ Friars Carse) | Yes | Yes | 64 | 0 | 0.00 | | | 1.481 | |
| 56001 (Usk @ Chainbridge) | Yes | Yes | 60 | 0 | 0.00 | | | 2.249 | |
| 62001 (Teifi @ Glanteifi) | Yes | Yes | 62 | 0 | 0.00 | | | 1.390 | |
| 12003 (Dee @ Polhollick) | Yes | Yes | 30 | 0 | 0.00 | | | 2.404 | |
| 84018 (Clyde @ Tulliford Mill) | Yes | Yes | 38 | 0 | 0.00 | | | 0.551 | |
| 23004 (South Tyne @ Haydon Bridge) | Yes | Yes | 62 | 0 | 0.00 | | | 0.409 | |
| 47001 (Tamar @ Gunnislake) | Yes | Yes | 65 | 1 | 1.54 | | | 0.212 | |
| 21003 (Tweed @ Peebles) | Yes | Yes | 62 | 2 | 3.23 | | | 0.941 | |

**Pooling group catchment descriptors**

| Station | Area | SAAR | FPEXT | FARL | URBEXT2000 | BFIHOST19 |
|---|---|---|---|---|---|---|
| 54028 (Vyrnwy @ Llanymynech) | 779.143 | 1339 | 0.052 | 0.969 | 0.001 | 0.412 |
| 84004 (Clyde @ Sills of Clyde) | 742.265 | 1223 | 0.062 | 0.964 | 0.002 | 0.407 |
| 79002 (Nith @ Friars Carse) | 797.705 | 1461 | 0.050 | 0.991 | 0.002 | 0.389 |
| 56001 (Usk @ Chainbridge) | 913.247 | 1367 | 0.044 | 0.980 | 0.006 | 0.559 |
| 62001 (Teifi @ Glanteifi) | 897.585 | 1379 | 0.049 | 0.995 | 0.005 | 0.463 |
| 12003 (Dee @ Polhollick) | 697.505 | 1231 | 0.038 | 0.986 | 0.000 | 0.404 |
| 84018 (Clyde @ Tulliford Mill) | 938.362 | 1205 | 0.062 | 0.966 | 0.002 | 0.404 |
| 23004 (South Tyne @ Haydon Bridge) | 749.895 | 1147 | 0.044 | 0.989 | 0.002 | 0.321 |
| 47001 (Tamar @ Gunnislake) | 920.220 | 1215 | 0.044 | 0.993 | 0.005 | 0.445 |
| 21003 (Tweed @ Peebles) | 698.120 | 1140 | 0.051 | 0.974 | 0.003 | 0.466 |

**Pooling Group Rejected Stations**

| Station | Distance | Years of data | QMED AM | L-CV Observed | L-CV Deurbanised | L-SKEW Observed | L-SKEW Deurbanised | Comments |
|---|---|---|---|---|---|---|---|---|

# UK Design Flood Estimation

## Summary of ESS/Pooled Estimation Analysis using the Flood Estimation Handbook Statistical Method

### Growth curve L-moments

| | | | |
|---|---|---|---|
| Rural L-CV: | 0.169 | Urban L-CV: | 0.169 |
| Rural L-Skewness: | 0.226 | Urban L-Skewness: | 0.226 |

**Rural fitted parameters**

| Distribution | Location | Scale | Shape | H | Bound |
|---|---|---|---|---|---|
| GL | 1.000 | 0.165 | -0.226 | | 0.270 |
| GEV | 0.911 | 0.240 | -0.086 | | -1.882 |
| KAP3 | 0.955 | 0.198 | -0.163 | -0.400 | -0.260 |

**Urban fitted parameters**

| Distribution | Location | Scale | Shape | H | Bound |
|---|---|---|---|---|---|
| GL | 1.000 | 0.165 | -0.226 | | 0.271 |
| GEV | 0.911 | 0.239 | -0.086 | | -1.872 |
| KAP3 | 0.955 | 0.198 | -0.163 | -0.400 | -0.258 |

**Goodness of fit**

GL: 0.8415 *
GEV: -0.8282 *
P3: -2.6526
GP: -4.8469
KAP3: 0.2665 *

** Distribution gives an acceptable fit (absolute Z value < 1.645)*

**Heterogeneity**

Standardised test value H2: -0.6387

*The pooling group is acceptably homogeneous and a review of the pooling group is not required.*

### Standardised growth curves

**Rural**

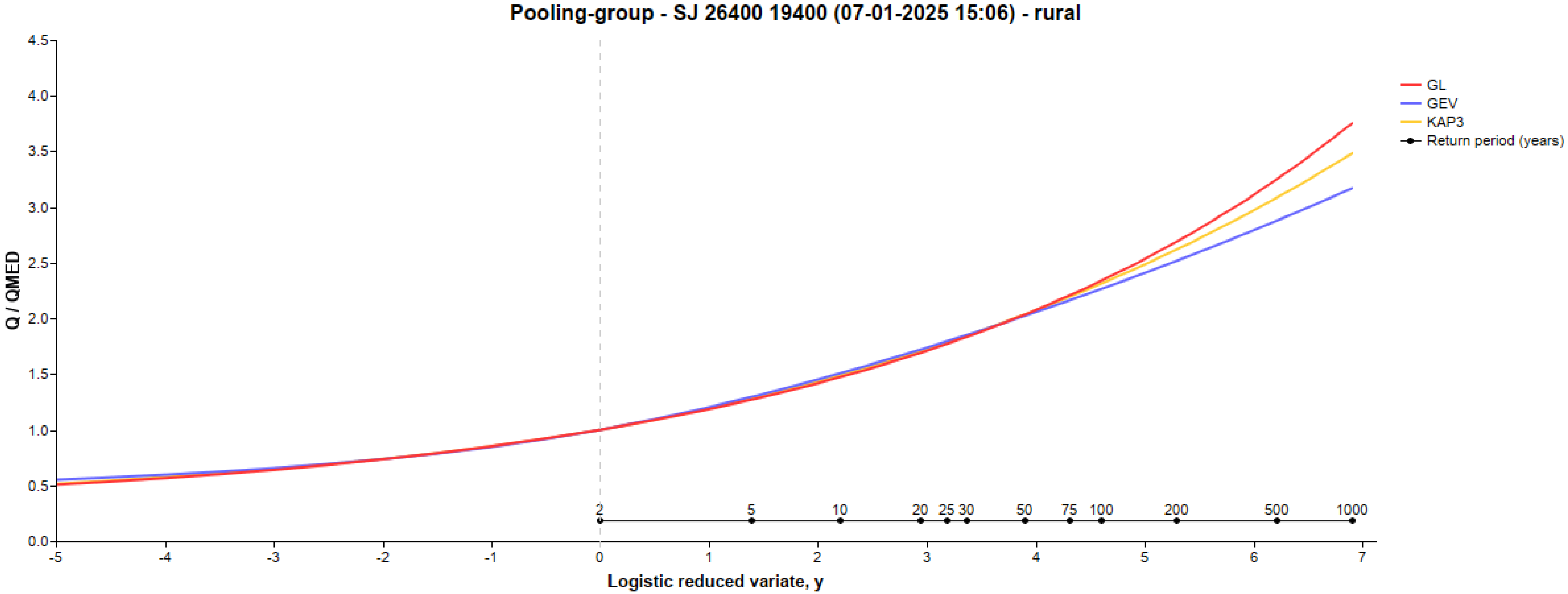
| Return period | GL | GEV | KAP3 |
|---|---|---|---|
| 2 | 1.000 | 1.000 | 1.000 |
| 5 | 1.269 | 1.294 | 1.280 |
| 10 | 1.470 | 1.506 | 1.487 |
| 20 | 1.691 | 1.722 | 1.708 |
| 25 | 1.769 | 1.793 | 1.783 |
| 30 | 1.834 | 1.852 | 1.846 |
| 50 | 2.031 | 2.022 | 2.033 |
| 75 | 2.204 | 2.161 | 2.191 |
| 100 | 2.335 | 2.263 | 2.310 |
| 200 | 2.689 | 2.518 | 2.619 |
| 500 | 3.248 | 2.878 | 3.084 |
| 1000 | 3.755 | 3.170 | 3.484 |

**Urban**

| Return period | GL | GEV | KAP3 |
|---|---|---|---|
| 2 | 1.000 | 1.000 | 1.000 |
| 5 | 1.269 | 1.294 | 1.280 |
| 10 | 1.470 | 1.505 | 1.487 |
| 20 | 1.691 | 1.721 | 1.707 |
| 25 | 1.768 | 1.793 | 1.783 |
| 30 | 1.834 | 1.852 | 1.846 |
| 50 | 2.031 | 2.021 | 2.032 |
| 75 | 2.203 | 2.161 | 2.191 |
| 100 | 2.335 | 2.262 | 2.310 |
| 200 | 2.688 | 2.517 | 2.619 |
| 500 | 3.248 | 2.878 | 3.084 |
| 1000 | 3.755 | 3.170 | 3.484 |

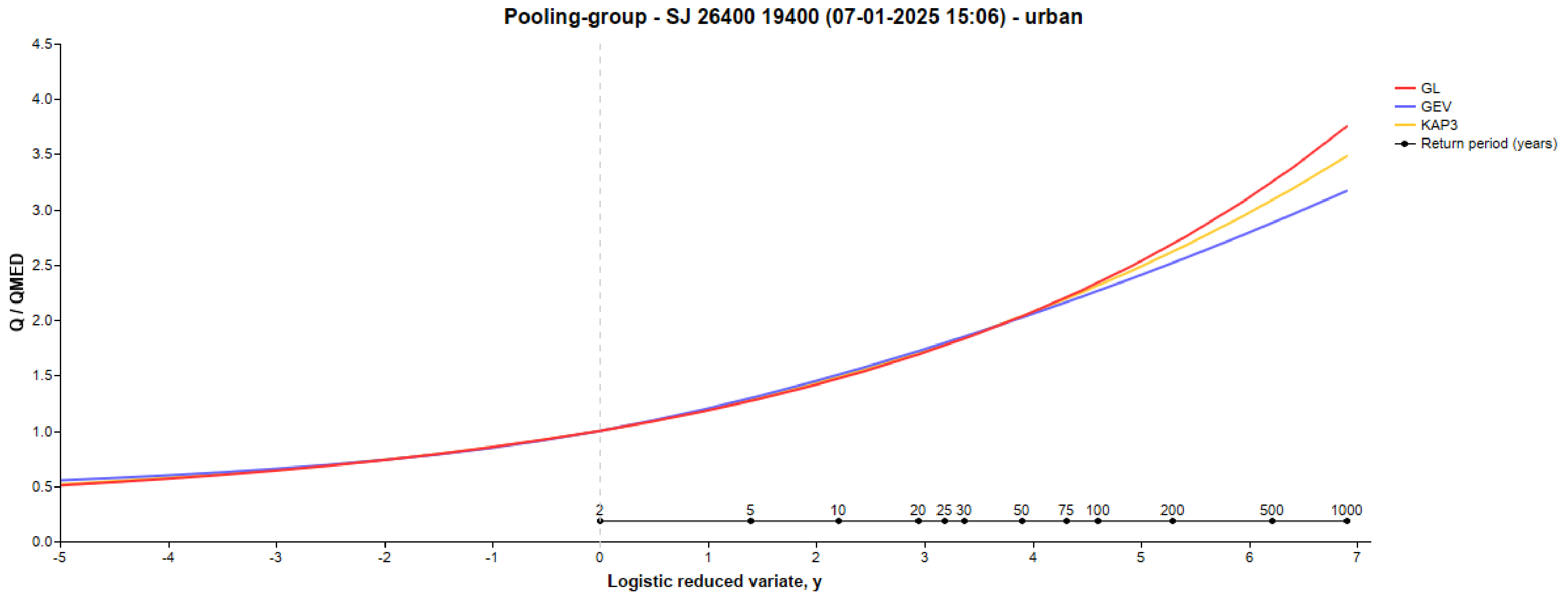
# UK Design Flood Estimation

## Summary of ESS/Pooled Estimation Analysis using the Flood Estimation Handbook Statistical Method



# UK Design Flood Estimation

## Summary of ESS/Pooled Estimation Analysis using the Flood Estimation Handbook Statistical Method



# UK Design Flood Estimation

## Summary of ESS/Pooled Estimation Analysis using the Flood Estimation Handbook Statistical Method

### QMED data and results

**Donor selection criteria**

| | |
|---|---|
| Only sites suitable for QMED: | Yes |
| URBEXT2000: | <0.030 |
| Donor adjusted FSE: | 1.084 |
| No. of donors: | 6 |

**Donor stations**

| Station | Distance | Use QMED obs deurbanised | QMED obs | QMED deurbanised | QMED CDs urban | QMED CDs rural |
|---|---|---|---|---|---|---|
| 54028 (Vyrnwy @ Llanymynech) | 0.10 | Yes | 264.248 | **264.011** | 315.134 | 315.134 |
| 54038 (Tanat @ Llanyblodwel) | 9.82 | Yes | 79.320 | **79.247** | 114.253 | 114.253 |
| 54005 (Severn @ Montford) | 12.13 | Yes | 307.379 | **306.027** | 532.007 | 532.007 |
| 67013 (Hirnant @ Plas Rhiwedog) | 17.14 | Yes | 24.081 | **24.081** | 37.842 | 37.842 |
| 67005 (Ceiriog @ Brynkinalt Weir) | 19.93 | Yes | 30.000 | **29.962** | 58.390 | 58.390 |
| 67015 (Dee @ Manley Hall) | 21.88 | Yes | 227.000 | **226.045** | 365.080 | 365.080 |

**Donor suitability**

| Station | Suitability for QMED | Suitability for pooling | Years | Non-flood years | Percentage non-flood years | Mann Kendall (MKZ) | MKZ significance (%) | Comments |
|---|---|---|---|---|---|---|---|---|
| 54028 (Vyrnwy @ Llanymynech) | Yes | Yes | 45 | 0 | 0.00 | | | |
| 54038 (Tanat @ Llanyblodwel) | Yes | Yes | 48 | 0 | 0.00 | | | |
| 54005 (Severn @ Montford) | Yes | Yes | 69 | 0 | 0.00 | | | |
| 67013 (Hirnant @ Plas Rhiwedog) | Yes | No | 12 | 2 | 16.67 | | | |
| 67005 (Ceiriog @ Brynkinalt Weir) | Yes | No | 24 | 0 | 0.00 | | | |
| 67015 (Dee @ Manley Hall) | Yes | Yes | 51 | 0 | 0.00 | | | |

**Donor catchment descriptors**

| Station | Area | Centroid X | Centroid Y | SAAR | FPEXT | FARL | URBEXT2000 | BFIHOST19 |
|---|---|---|---|---|---|---|---|---|
| FEH_Catchment_Descriptors_326400_319400_v5_0_1 @ SJ 26400 19400) | 783.467 | 307842 | 318668 | 1335 | 0.053 | 0.969 | 0.001 | 0.413 |
| 54028 (Vyrnwy @ Llanymynech) | 779.143 | 307743 | 318661 | 1339 | 0.052 | 0.969 | 0.001 | 0.412 |
| 54038 (Tanat @ Llanyblodwel) | 241.125 | 312720 | 327196 | 1274 | 0.038 | 0.996 | 0.001 | 0.427 |
| 54005 (Severn @ Montford) | 2026.770 | 310948 | 306939 | 1147 | 0.092 | 0.977 | 0.004 | 0.444 |
| 67013 (Hirnant @ Plas Rhiwedog) | 32.470 | 296007 | 331068 | 1756 | 0.018 | 1.000 | 0.000 | 0.351 |
| 67005 (Ceiriog @ Brynkinalt Weir) | 111.718 | 317500 | 336107 | 1198 | 0.023 | 1.000 | 0.001 | 0.403 |
| 67015 (Dee @ Manley Hall) | 1008.740 | 303097 | 340024 | 1367 | 0.046 | 0.934 | 0.004 | 0.402 |

# UK Design Flood Estimation

## Summary of ESS/Pooled Estimation Analysis using the Flood Estimation Handbook Statistical Method

**Unused Donor stations**

| Station | Distance | URBEXT | Use QMED obs deurbanised | QMED obs | QMED deurbanised | QMED CDs urban | QMED CDs rural | Centroid X | Centroid Y | Area | SAAR | BFIHOST19 | FARL | Years of data | QMED suitability | Pooling suitability |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 64001 (Dyfi @ Dyfi Bridge) | 26.49 | 0.001 | Yes | 321.713 | **321.488** | 323.402 | 323.402 | 284142 | 306845 | 464.605 | 1835 | 0.413 | 0.995 | 59 | Yes | No |
| 64011 (Cerist @ Llaw'r Cae) | 27.20 | 0.000 | Yes | 6.137 | **6.137** | 9.655 | 9.655 | 280806 | 315666 | 5.350 | 2159 | 0.364 | 1.000 | 25 | Yes | No |
| 67018 (Dee @ New Inn) | 27.40 | 0.000 | Yes | 77.099 | **77.073** | 75.025 | 75.025 | 283267 | 330791 | 53.383 | 2022 | 0.289 | 1.000 | 23 | Yes | No |
| 54014 (Severn @ Abermule) | 29.81 | 0.004 | Yes | 188.094 | **187.241** | 217.686 | 217.686 | 300198 | 289854 | 574.538 | 1256 | 0.420 | 0.970 | 53 | Yes | Yes |

**QMED**

Rural: 261.626 $m^3/s$

Urban: 261.861 $m^3/s$

# UK Design Flood Estimation

## Summary of ESS/Pooled Estimation Analysis using the Flood Estimation Handbook Statistical Method

### Flood Frequency Curve

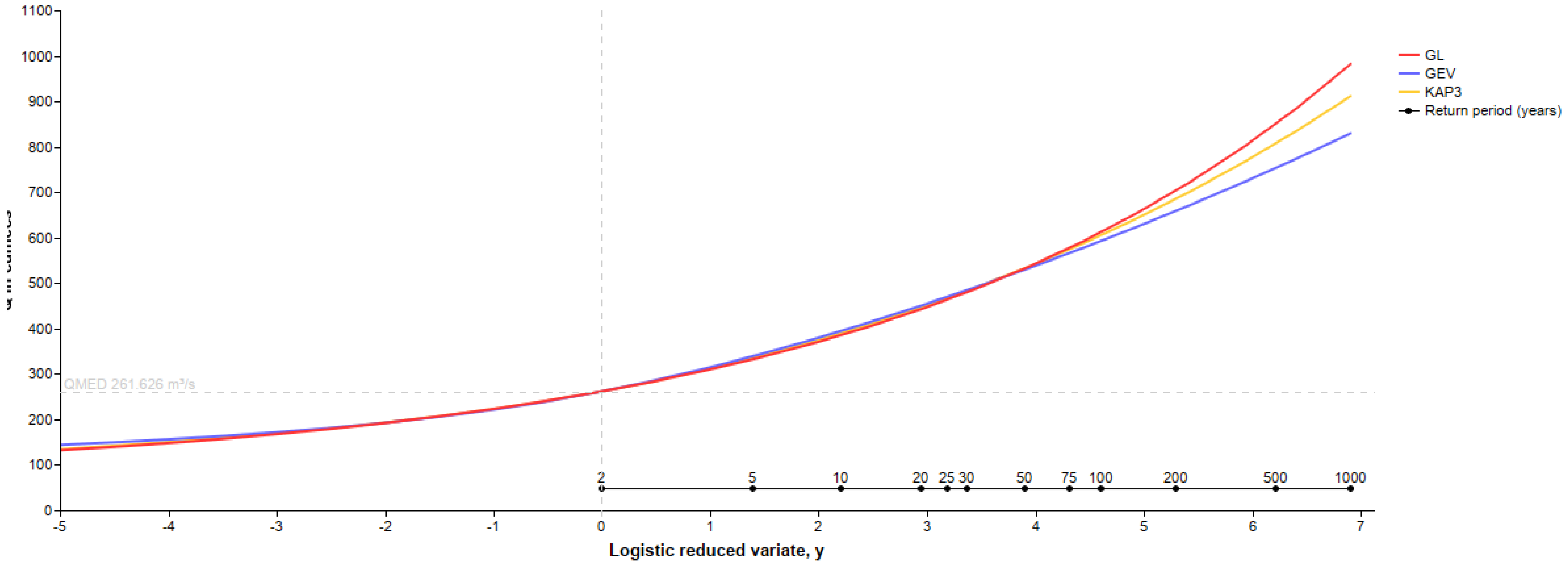
**Rural Flood Frequency Curve**

| Return period | GL (m³/s) | GEV (m³/s) | KAP3 (m³/s) |
|---|---|---|---|
| 2 | 261.626 | 261.626 | 261.626 |
| 5 | 332.017 | 338.654 | 334.819 |
| 10 | 384.671 | 393.935 | 388.999 |
| 20 | 442.529 | 450.413 | 446.797 |
| 25 | 462.719 | 469.070 | 466.499 |
| 30 | 479.875 | 484.520 | 483.053 |
| 50 | 531.453 | 528.896 | 531.829 |
| 75 | 576.512 | 565.365 | 573.300 |
| 100 | 610.953 | 591.960 | 604.343 |
| 200 | 703.433 | 658.667 | 685.183 |
| 500 | 849.767 | 752.992 | 806.788 |
| 1000 | 982.286 | 829.375 | 911.516 |

**Urban Flood Frequency Curve**

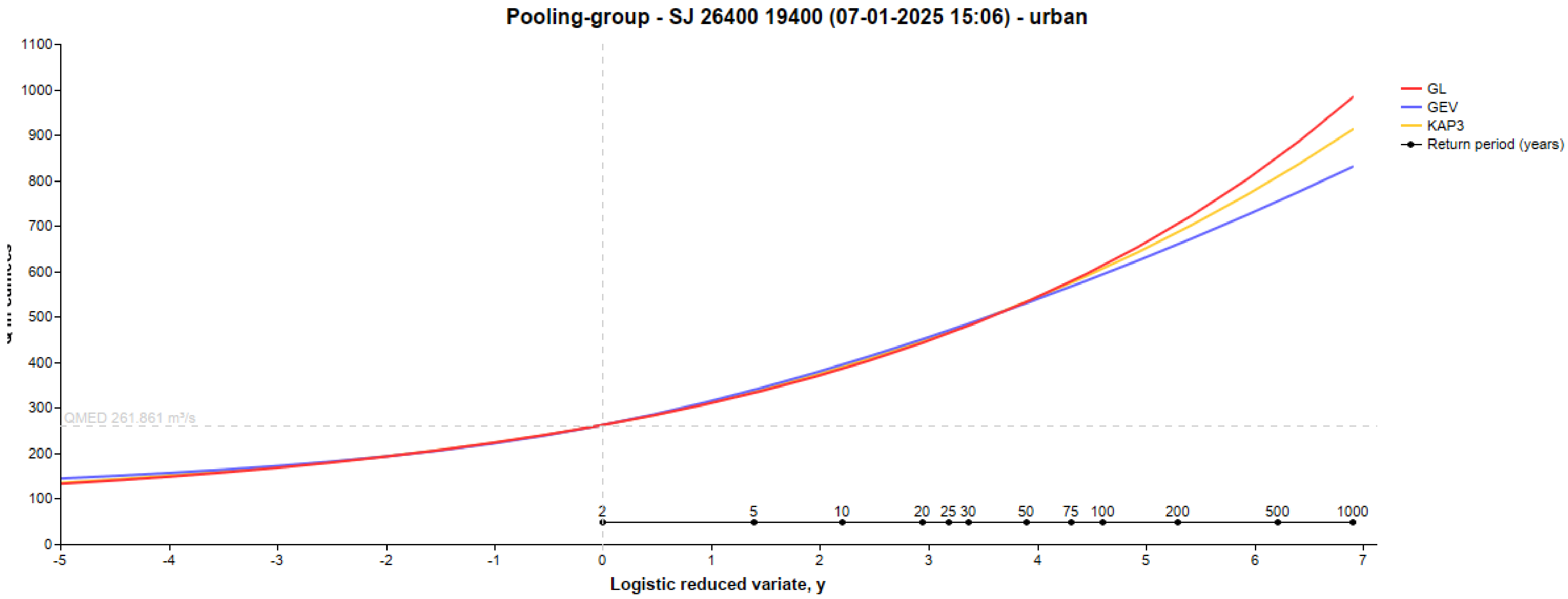
| Return period | GL (m³/s) | GEV (m³/s) | KAP3 (m³/s) |
|---|---|---|---|
| 2 | 261.861 | 261.861 | 261.861 |
| 5 | 332.278 | 338.916 | 335.080 |
| 10 | 384.961 | 394.228 | 389.289 |
| 20 | 442.857 | 450.748 | 447.128 |
| 25 | 463.062 | 469.421 | 466.845 |
| 30 | 480.232 | 484.885 | 483.413 |
| 50 | 531.852 | 529.304 | 532.232 |
| 75 | 576.952 | 565.812 | 573.745 |
| 100 | 611.426 | 592.439 | 604.820 |
| 200 | 704.003 | 659.232 | 685.753 |
| 500 | 850.508 | 753.697 | 807.518 |
| 1000 | 983.199 | 830.208 | 912.399 |

**Pooling-group - SJ 26400 19400 (07-01-2025 15:06) - rural**



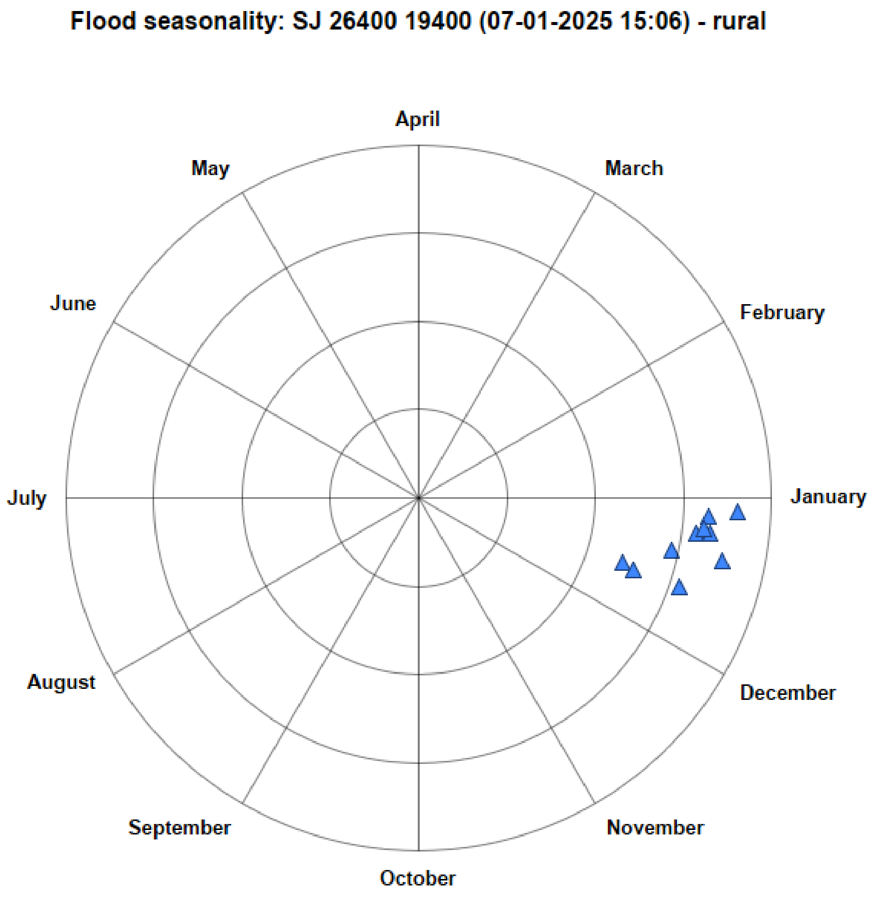
# UK Design Flood Estimation

## Summary of ESS/Pooled Estimation Analysis using the Flood Estimation Handbook Statistical Method



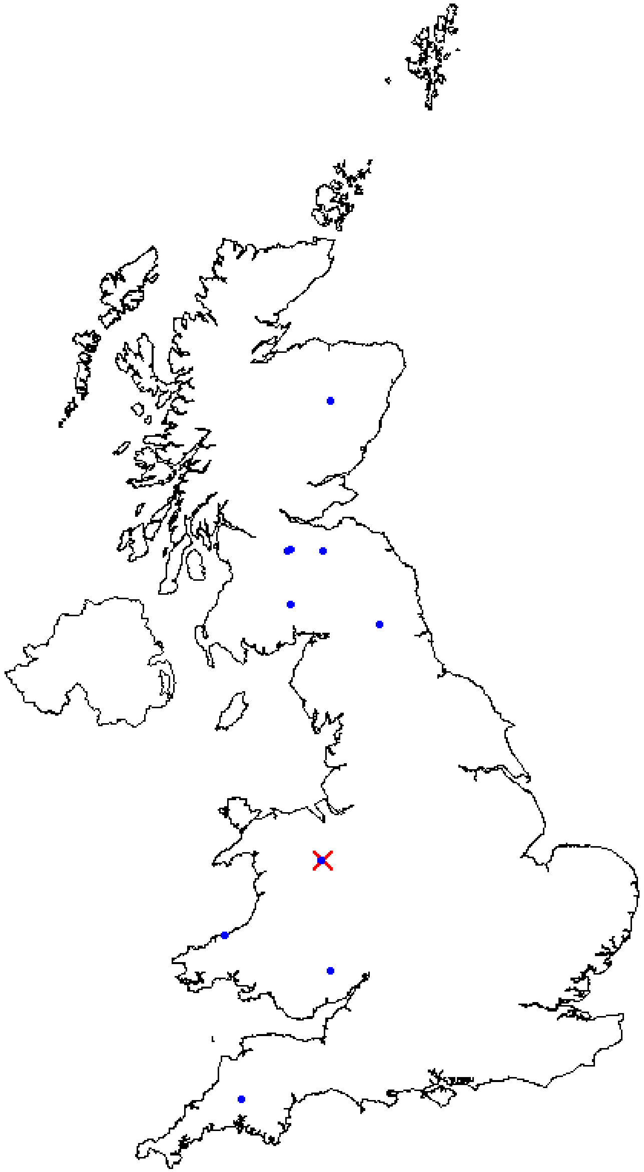
### Appendix

**Station record parameters**



# UK Design Flood Estimation

## Summary of ESS/Pooled Estimation Analysis using the Flood Estimation Handbook Statistical Method

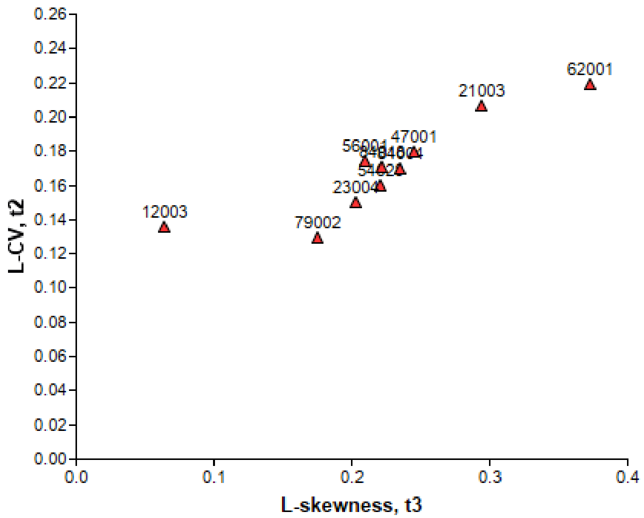


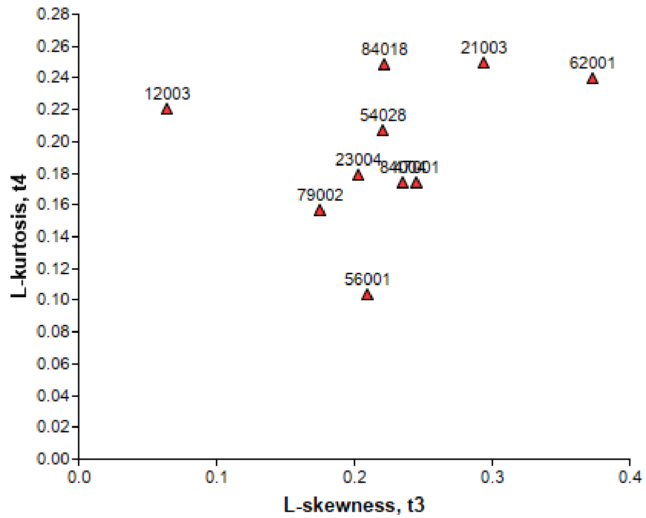
WINFAP Version: 5.2.9014 (11448)

# UK Design Flood Estimation

## Summary of ESS/Pooled Estimation Analysis using the Flood Estimation Handbook Statistical Method

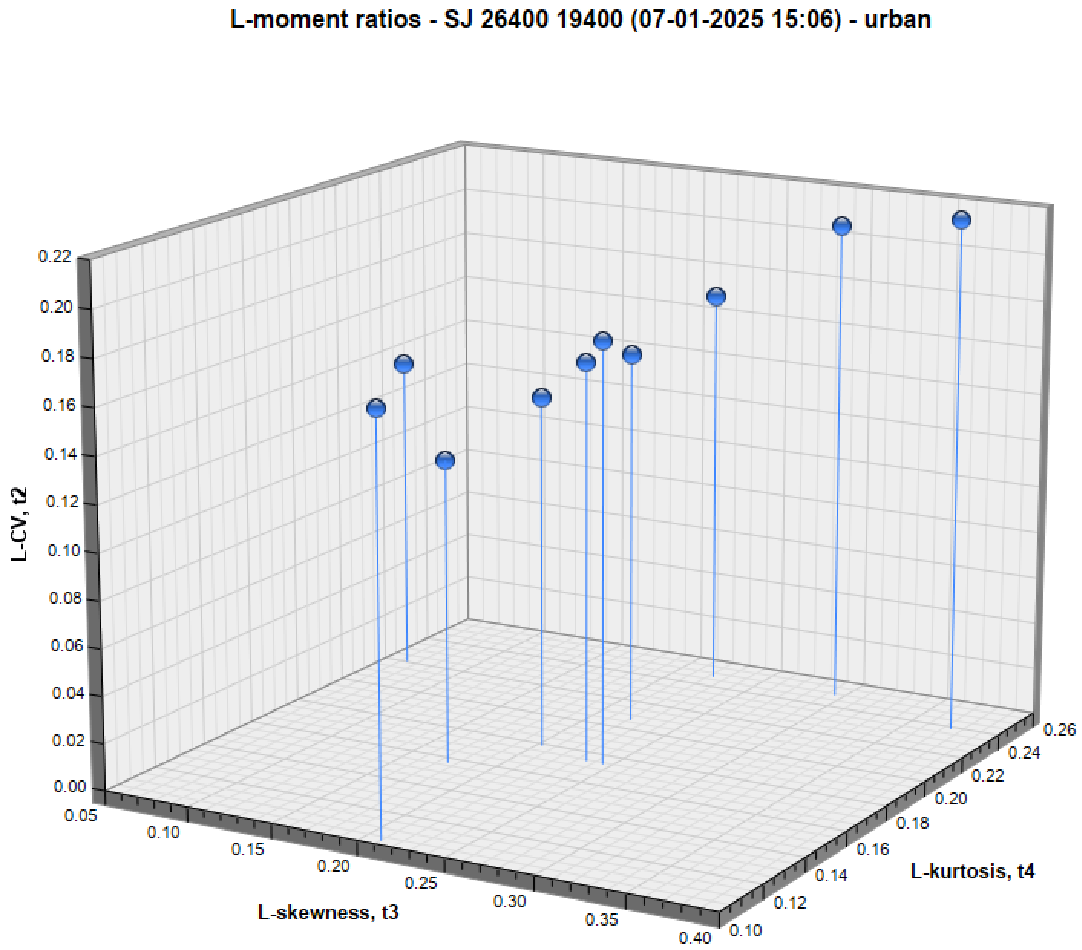
**L-moment ratios - SJ 26400 19400 (07-01-2025 15:06) - urban**



# UK Design Flood Estimation

## Summary of ESS/Pooled Estimation Analysis using the Flood Estimation Handbook Statistical Method

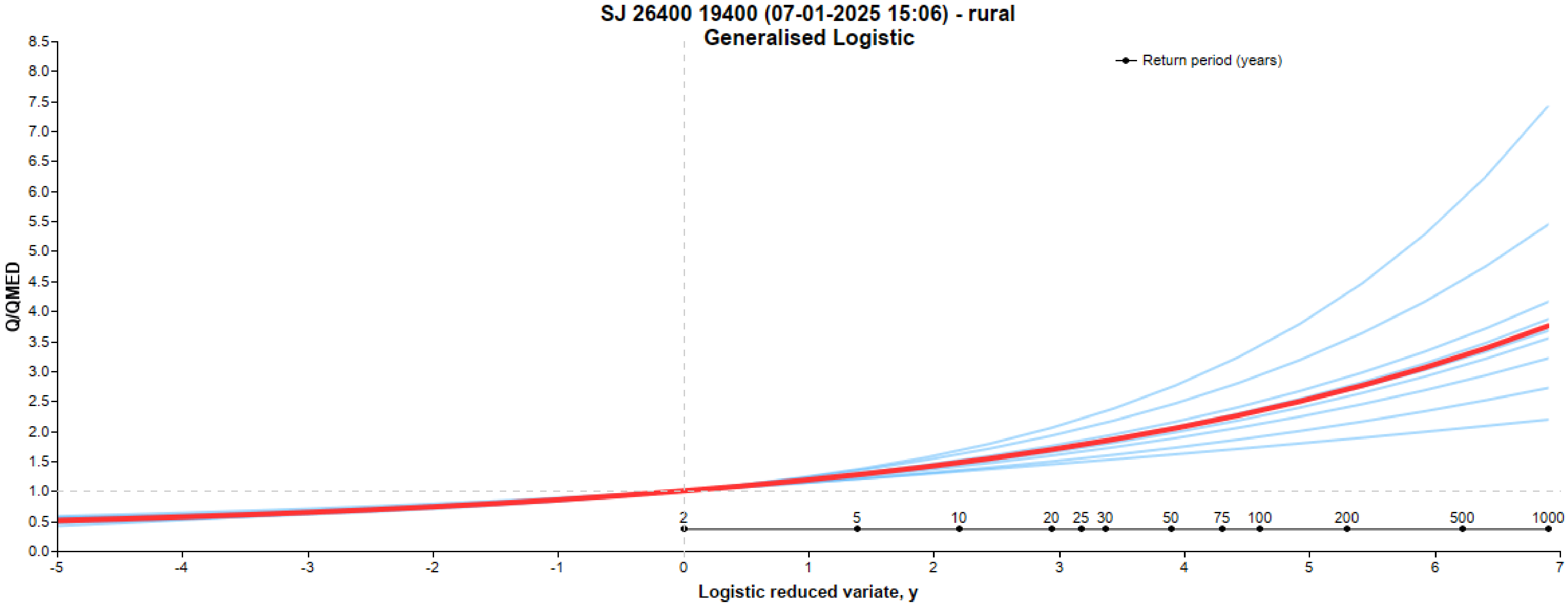



WINFAP Version: 5.2.9014 (11448)

# UK Design Flood Estimation

## Summary of ESS/Pooled Estimation Analysis using the Flood Estimation Handbook Statistical Method

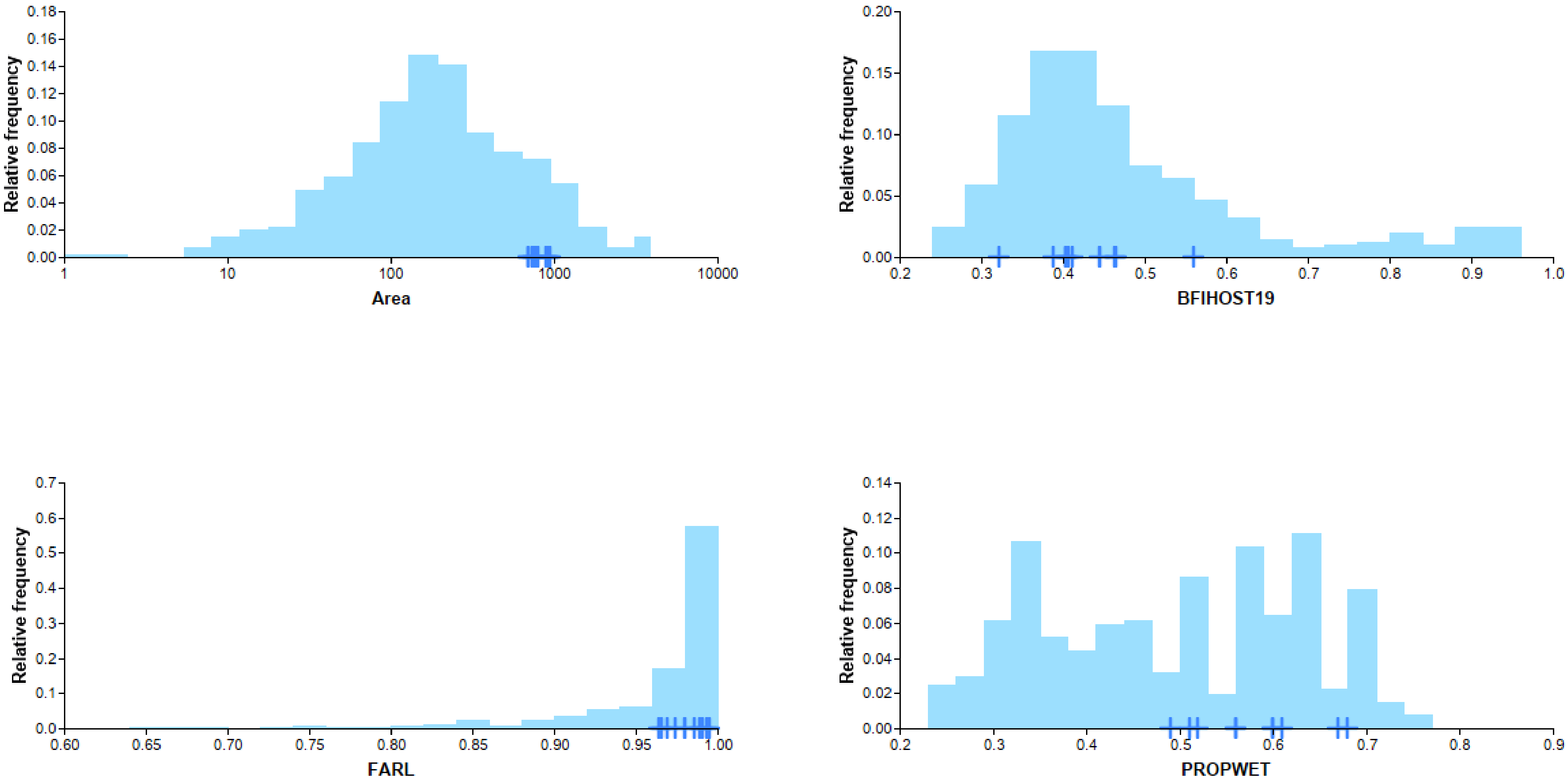
**Pooling group growth curves**



# UK Design Flood Estimation

## Summary of ESS/Pooled Estimation Analysis using the Flood Estimation Handbook Statistical Method

### Catchment descriptors



# UK Design Flood Estimation

## Summary of ESS/Pooled Estimation Analysis using the Flood Estimation Handbook Statistical Method