Water Management Strategy in Aberhirnant Welsh Government Woodland Estate

Report No: 771

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Contents

List of figures

List of tables

Crynodeb gweithredol

Cefndir y prosiect

Comisiynwyd JBA Consulting gan Cyfoeth Naturiol Cymru (CNC) yn 2023 i gynnal astudiaeth o floc o Ystad Goetir Llywodraeth Cymru, sef Aberhirnant yng Ngwynedd, er mwyn ymchwilio i'r swyddogaeth geomorffolegol ac ecolegol bresennol ar draws yr ardal astudio er mwyn nodi ystod o ymyriadau ar gyfer rheoli'r dalgylch mewn modd integredig. Mae JBA wedi datblygu strategaeth rheoli dŵr a chynllun cyflawni cyfatebol ar gyfer Coedwig Aberhirnant, a gyflwynir mewn adroddiad tystiolaeth ac allbynnau systemau gwybodaeth ddaearyddol cysylltiedig.

Mae'r adroddiad hwn yn rhan o raglen ehangach i sicrhau gweithrediad rheoli dalgylchoedd yn integredig mewn blociau coedwigaeth eraill ar draws Ystad Goetir Llywodraeth Cymru. Mae'n cynnig nifer o atebion ar sail natur ar gyfer yr amgylchedd afonol a dŵr i alluogi gwelliant, adferiad a gwell gwydnwch trwy fynd i'r afael â phwysau ac effeithiau ar draws y dalgylch, gan gynnwys addasiadau ffisegol, rhywogaethau estron goresgynnol a dirywiad llystyfiant glannau afonydd. Mae'r cynllun yn nodi cyfleoedd i arafu'r llif (arafu llifoedd dŵr a gwaddod) a hefyd i gyflawni manteision amgylcheddol eraill ar draws yr ardal astudio. Bydd angen mireinio'r opsiynau arfaethedig ar gyfer arafu llifoedd dŵr a gwaddod ymhellach trwy waith dichonoldeb a dylunio yn y dyfodol cyn eu rhoi ar waith ar lawr gwlad.

Bydd yr amserlenni ar gyfer gweithredu'r opsiynau a nodwyd yn dibynnu ar lwyddiant y cydweithrediad hwn ac argaeledd ffactorau fel cyllid ac adnoddau, yn ogystal ag ymateb geomorffolegol ac ecolegol i'r gwahanol opsiynau arafu ar gyfer dŵr a gwaddod.

Canfyddiadau allweddol

Pwysau allweddol ar yr amgylchedd dŵr	Disgrifiad
Amseru gweithrediadau llwyrdorri a theneuo yn y goedwig	Gall arferion torri coed sy'n defnyddio peiriannau trwm achosi aflonyddwch i'r ddaear, gan arwain at ddadleoli gwaddod mân a chywasgu priddoedd, gan arwain yn ei dro at lai o fandylledd a rhyddhau cyfansoddion ffosffad a nitrogen sy'n lleihau ansawdd y dŵr trwy asideiddio.
Addasiadau i'r glannau	Mae gosod peirianneg galed, fel caergewyll, yn cyfyngu ar erydu ochrol a/neu symudiad y cwrs dŵr ac yn arwain at golli cynefin ar y glannau.
Rhywogaethau estron goresgynnol	Gallai presenoldeb rhywogaethau estron goresgynnol arwain at iddynt ledaenu o fewn y coetir a'r ardal gyfagos. Byddai hyn yn newid cynefinoedd a chyfansoddiad y rhywogaethau sy'n bresennol yn y coetir.

Pwysau allweddol ar yr amgylchedd dŵr	Disgrifiad
Pwysau rheoli amaethyddol	Mae pori dwys yn atal twf llystyfiant glannau afonydd. O ganlyniad, nid oes parth clustogi i hidlo maetholion yn y dŵr cyn iddo gael ei ollwng i nentydd a'r brif afon, gan felly leihau ansawdd y dŵr. Gall arferion amaethyddol hefyd arwain at gynnydd mewn asideiddio o fewn afon Hirnant a rhyddhau gwaddodion mân.
Pontydd	Gall gosod adeiledd sy'n rhychwantu rhan o sianel arwain at golli cynefinoedd yn uniongyrchol, cyflymiad mewn cyflymderau yn y sianel, a chynyddu sgwrio o amgylch ategweithiau'r bont, gan annog rhyddhau gwaddod yn y sianel.
Diffyg llystyfiant / llystyfiant wedi'i ddiraddio ar hyd glannau afonydd	Ni fydd dŵr yn cael ei hidlo drwy barth clustogi glannau afonydd gweithredol â chysylltiadau da; o ganlyniad, bydd yn eithaf asidig, gan lygru a diraddio ansawdd y dŵr.
Draeniau ffyrdd	Mae dŵr o ddarn mawr o lethr yn cael ei ddargyfeirio trwy ddraeniau'r ffordd i geuffos, sy'n cyfeirio dŵr tuag at y brif afon, ac, o ganlyniad, gallai'r perygl o lifogydd gynyddu i lawr yr afon.
Deunydd ar ymyl y ffordd wedi'i ddyddodi	Yn ystod glaw trwm, gall rhywfaint o'r gwaddod hwn sydd wedi'i ddyddodi gael ei ailsymud ac ailymuno â'r cwrs dŵr a'r brif afon, gan arwain at ostyngiad yn ansawdd y dŵr a lefelau tyrfedd uwch yn y dŵr.
Deunydd wedi'i gloddio	Yn ystod glaw trwm, gall rhywfaint o'r deunydd hwn sydd wedi'i gloddio gael ei ailsymud ac ailymuno â'r cwrs dŵr a'r brif afon, gan arwain at ostyngiad yn ansawdd y dŵr a lefelau tyrfedd uwch yn y dŵr.
Cwlfertau	Gall disodli rhan o sianel agored ag adrannau wedi'u sianelu arwain at golled uniongyrchol o gynefin a diffyg cysylltedd hydredol ac ochrol.
Deunydd rhydd o'r ffordd	Gall mewnbynnau gwaddod mân i ffrydiau blaenddwr a sianeli draenio arwain at ostyngiadau yn ansawdd dŵr a lefelau tyrfedd uwch yn y dŵr.

Pwysau allweddol ar yr amgylchedd dŵr	Disgrifiad
Draeniau a ffosydd yn y goedwig	Mae draeniau coedwig yn cyfrannu at gludo'r llif a gwaddodion yn gyflymach i lawr y llethr, tuag at y brif afon. Gall hyn arwain at lefelau dŵr uwch yn y sianel a risg uwch o lifogydd i lawr yr afon.

Cyfleoedd posibl i gyflawni amcanion y prosiect

- Ymgorffori arferion coedwigaeth cynaliadwy
- Gwella lleoliad deunydd ar ymyl y ffordd
- Gwaredu deunydd wedi'i gloddio
- Clirio'r dalbwll
- Ychwanegu dalbwll
- Difodi unrhyw rywogaethau estron goresgynnol
- Gostwng y glannau
- Ychwanegu sypynnau rhostir
- Gosod byndiau bach
- Ychwanegu clogfeini
- Ychwanegu deunydd prennaidd mawr / rhwystrau mandyllog
- Ychwanegu byrnau neu geobilen
- Cynyddu llystyfiant ar lannau afonydd
- Gosod wadiau gwreiddiau
- Gosod cwlferi newydd

Isod mae cyfleoedd ychwanegol y gellid eu gweithredu o fewn yr ardal astudio a fyddai hefyd yn cyd-fynd ag amcanion y prosiect. Nid yw'r cyfleoedd hyn wedi'u cynnwys yn y tabl cyfleoedd mwy gan na chanfuwyd unrhyw leoliadau addas ar gyfer y nodweddion hyn yn ystod yr ymweliad â'r safle.

Cyfleoedd ychwanegol

- Cynllunio gweithrediadau coedwig ar raddfa dalgylch
- Cynhyrchu cynlluniau rheoli dŵr dalgylch
- Gosod draeniau siâp J

Executive summary

Project background

In 2023 JBA Consulting was commissioned by Natural Resources Wales (NRW) to undertake a study of a Welsh Government Woodland Estate (WGWE) block, Aberhirnant in Gwynedd, to investigate existing geomorphological and ecological functioning across the study area in order to identify a range of Integrated Catchment Management interventions. JBA have developed a Water Management Strategy (WMS) and corresponding Delivery Plan (DP) for Aberhirnant Forest, presented in an evidence report and accompanying GIS outputs.

This report is part of a wider programme to implement integrated catchment management in other forestry blocks across the WGWE. It proposes a number of nature based solutions for the riverine and water environment to enable enhancement, recovery and improved resilience by addressing pressures and impacts across the catchment including physical modifications, invasive non-native species (INNS) and riparian vegetation degradation. The plan identifies opportunities to slow the flow (attenuate water and sediment) and also deliver other environmental benefits across the study area. The options for water and sediment attenuation proposed will need to be further refined through future feasibility and design work prior to any implementation on the ground.

Timescales for implementation of the identified options will depend on the success of this collaboration and the availability of factors such as funding and resources, as well as geomorphological and ecological response to the different water and sediment attenuation options.

Key findings

Key pressures on the water environment	Description
Timing of clearfell and thinning forest operations	Felling practices with the use of heavy machinery can cause ground disturbances, resulting in fine sediment displacement, compaction of soils leading to reduced porosity and a release of phosphate and nitrogen compounds that deplete water quality through acidification.
Bank modification	Installing hard engineering, such as gabion baskets, limit the lateral erosion and or migration of the watercourse and results in a loss of bankside habitat.

Key pressures on the water environment	Description
Invasive Non-Native Species	The presence of INNS could result in it spreading within the woodland and surrounding area. This would alter the habitats and composition of species present within the woodland.
Agricultural management pressures	Intensive grazing prevents the growth of a riparian vegetation. As a result, there is no buffer zone to filter out nutrients in water before it is discharged into streams and the main river, therefore water depleting water quality. Agricultural practices can also lead to increase acidification within the Afon Hirnant and fine sediment release.
Bridges	Installing a structure that spans a section of channel can result in direct habitat loss, acceleration in in-channel velocities and increase scour around the bridge abutments, encouraging the release of in-channel sediment.
Lack of/degraded riparian vegetation	Riparian vegetation, with a mix of broadleaf native trees, shrubs and grasses, creates an important transition zone between aquatic and terrestrial environments. Riparian woodlands are crucial for controlling erosion, improving water quality, providing habitat for wildlife, and supporting the food chain for aquatic ecosystems. Without riparian vegetation, polluted runoff from forestry operations can enter the watercourse directly, leading to acidic, polluted, and degraded water quality due to the lack of filtering capacity.
Road drains	Forestry roadside drains artificially concentrate and accelerate water draining from large sloping areas of woodland. These drains are often connected to streams and rivers and can lead to increased downstream flood risk and degradation of water quality from fine sediment dispersal.

Key pressures on the water environment	Description
Deposited roadside material	During heavy rainfall events some of this deposited sediment could be remobilised and re-enter and watercourse and the main river resulting in decreases in water quality and increased water turbidity.
Excavated material	During heavy rainfall events some of this excavated material could be remobilised and re-enter and watercourse and the main river resulting in decreases in water quality and increased water turbidity.
Culverts	Replacing a section of open channel with culverted sections can result in a direct loss of habitat and a lack of longitudinal and lateral connectivity.
Loose road material	Fine sediment inputs into headwater streams and drainage channels can result in decreases in water quality and increased water turbidity.
Forest drains and ditches	Forest drains contribute to a quicker conveyance of flow and sediment transport downslope, towards the main river. Can result in increased in-channel water levels and an increased risk of flooding downstream.

Potential opportunities to meet project objectives

- Embed Sustainable Forest practices
- Improve placement of roadside material
- Remove excavated material
- Clear catchpit
- Add catchpit
- Eradicate INNS
- Bank lowering
- Add heath bundles
- Micro bund
- Add boulders
- Add large woody material/leaky barriers
- Add gales or geomembrane

- Increase riparian vegetation
- Install root wads
- Culvert replacement

Below are additional opportunities that could be implemented within the study area that would also align with project objectives. These opportunities have not been included within the larger opportunity table as there were no suitable locations found for these features during the site visit.

Additional opportunities

- Plan forest operations at catchment scale
- Produce catchment water management plans
- Implementation of J-shaped drains

1. Introduction

1.1 Study background

Natural Resources Wales (NRW) is the statutory organisation responsible for environmental management in Wales. These functions include the management of the freshwater environment including protected sites designated under UK legislation and of European/international (Sites of Special Scientific Interest (SSSIs), Special Protection Areas (SPAs) and Special Areas of Conservation (SACs)) and water bodies under the Water Framework Directive. An important duty of NRW is the requirement for the Sustainable Management of Natural Resources specified by the Environment Act (Wales) 2016.

The freshwater environment in Wales is under significant threat from multiple pressures, including land drainage, physical modification, water pollution, invasive non-native species and climate change. As with any land use, forestry can be managed and designed to improve and restore water quality, wetland habitats, and the hydromorphology of rivers in addition to providing further resilience to communities by reducing flood risk.

In Wales, there has been significant, beneficial re-design of Welsh Government Woodland Estate (WGWE) woodlands and large-scale riparian improvements and projects over the last 20 years. This includes implementing the River Basin Management Plan (RBMP) requirements by changing forest design and felling through low impact and clear-fell systems and reduced pesticide and fertiliser use.

At the same time, it is recognised that there are many opportunities on the WGWE and in the wider catchment to exceed the UK Forestry Standard and associated Practice Guides to “slow the flow” of water on the estate to deliver benefits for nature, climate and people and to improve watercourse habitat to benefit protected species, such as through enhanced riparian habitat and improvements in hydrological connectivity through culvert modification/removal. The relevant practice guides include:

- Forest Research (2022). Designing and managing forests and woodlands to reduce flood risk. UK Forestry Standard Practice Guide.

- Forestry Commission (2019). Managing forest operations to protect the water environment. Practice Guide.

Integrated Catchment Management is a mechanism that can be used to address pressures on the water environment, such as those caused through forestry management and other land management in the study area, to achieve multiple benefits. According to NRW, this includes a suite of natural flood management interventions and river and habitat restoration solutions.

It involves providing a suite of interventions that apply the principles of Sustainable Management of Natural Resources (SMNR) and thereby enable the recovery and resilience of the water environment.

In 2023, Natural Resources Wales (NRW) commissioned JBA Consulting to undertake a study of the Aberhirnant WGWE block in Gwynedd. The purpose of the study was to assess the existing hydrological, geomorphological and ecological functioning of the area, and to use this evidence to develop a range of potential Integrated Catchment Management interventions to consider for future implementation.

1.2 Study aims and objectives

1.2.1 Aim

The aim of this study is to provide proposals for nature based solutions that can aid the recovery and increase the resilience of the riverine and water environment in Aberhirnant Forest by restoring or enhancing natural features and function in the catchment, in line with, and where possible, going beyond the water management requirements set out in the UK Forestry Standard and associated Practice Guides. This will deliver multiple benefits including flood attenuation, biodiversity and geomorphology enhancements, robust and resilient riparian zones and water quality improvements. This study will help to deliver Integrated Catchment Management through developing a Water Management Strategy (WMS) and corresponding Delivery Plan (DP) for Aberhirnant Forest. The WMS will set the long-term vision for managing water on the Forestry Block, by bringing all the water management elements (see bullet points listed below) into one overarching strategy. This will then inform a Delivery Plan for the block, which can be easily adopted and used elsewhere to support ongoing forestry planning and operations.

1.2.2 Objectives

The primary objectives of the study are to:

- Carry out a Geomorphological and Ecological Assessment to identify opportunities, sensitivities, hazards to water quality/runoff, and 'take stock' of current conditions.
- Apply the principles, measures and objectives of the documents below in the Evidence Reports:
    - Aberhirnant Forest Resource Plan (FRP)
    - Relevant UK Forestry Standards
    - Forestry Practice Guides, (particularly Designing and managing forests and woodlands to reduce flood risk),

    - National Flood Risk Management Strategy
- Use the above to generate an overarching Water Management Strategy and Delivery Plan:
    - The WMS will be presented in a map format similar to the FRP Maps:
        - The WMS will include a detailed map of all the watercourse and drainage network and infrastructure and assets.
        - The WMS will be extracted from a prioritised list of interventions. This will take into account the benefits, such as habitat / species (which have been recorded in the local area or may have the potential to utilise the site) / water quality and flood reduction, how they deliver on the FRP objectives and the impacts such as commercial impact, and ease of delivery (i.e., access).
    - The DP will be presented in a table format:
        - The DP will identify whether each WMS component is a Business-as-Usual (BAU) activity or a Restoration Opportunity for freshwater habitat creation or to minimise flood risk and downstream water quality impacts. BAU activity is considered complying with UKFS and practice guides. The Delivery Plan table will be a working document and should be updated by NRW to identify how each WMS component will be delivered, by whom and when.
        - The DP will use the 5-year time periods of forestry planning starting with 2022-26.
- For the two evidence reports, include an explanation of the methodology and approximate costings for the interventions. It will also consider suitable low-cost monitoring of the effectiveness of the interventions.
- Inform NRW forestry colleagues of this project by delivering a presentation of the work undertaken and inviting feedback.

Table 1-1 shows a summary of the FRP deliverable objectives for Aberhirnant Forest (Aberhirnant and Llangower Forest Resource Plan).

Table 1-1: Summary of the FRP deliverable objectives for Aberhirnant Forest

Number	Objectives
1	Diversify the species composition of the forest by promoting a more diverse restocking strategy, which will include more variety of native broadleaves and productive conifer crops.
2	Improve the internal structure of the forest by developing age class diversity, variation of tree sizes and mixtures of species within stands.
3	Diversify woodland types within the forest, by increasing the variety of coniferous woodland and the expansion of native and riparian woodland habitats, which will help to improve connectivity within the forest and provide opportunities for linking to woodland networks outside of the forest in Cwm Hirnant and around Bala Lake.
4	Remove any larch infected with Phytophthora ramorum and plan for the eventual removal of remaining areas of significant larch under the Larch Reduction Strategy.
5	Maintain the long-term commercial viability of the forest, by planning a sustainable supply of timber. Improve timber quality and diversify products to more local markets.
6	Invest in forest infrastructure to provide better access to allow for more Low Impact Silvicultural Systems and thinning management.

Number	Objectives
7	Safeguard current timber haulage routes and explore practical access routes to isolated forest blocks in the Hirnant Valley.
8	Create a diverse permanent forest structure and ecosystem that includes riparian and native woodland, natural reserves and long-term retentions, with more successional woodland and open habitats along forest roads and rides where natural processes can take place.
9	Increase the quantity of deadwood in the forest, which supports a diverse biota within the forest ecosystem.
10	Manage the boundary between the forest and the Berwyn and South Clwyd SAC/SPA for the benefit and favourable condition of dry heath and blanket bog habitats and protected birds including raptors and Black Grouse. Consider different options for management such as native successional woodland buffer zones to minimise the impact of seeding conifers on the SAC
11	Expand the existing riparian woodland network to provide better buffering against harvesting operations and to help improve the water quality in freshwater ecosystems.
12	Ensure compliance with the requirements of the Water Framework Directive when undertaking operational activities by following best practice as outlined in the 'UK Forest Standard - Forest and Water Guidelines' to protect water quality and freshwater ecosystems within the forest.
13	Plan smaller felling coupes and use Low Impact Silvicultural Systems where possible, to help minimise the impact on water quality in the wider Dee LIFE project area, by reducing the risk of sedimentation, peak flows, as well as reducing the visual impacts on the landscape.
14	Restore all Ancient Woodland Sites through the gradual removal of conifers over time, using Low Impact Silvicultural Systems and thinning management where possible.
15	Protect all monuments and historical features when carrying out forest management operations.
16	Consider the visual impact of management operations and long-term proposals on views within Snowdonia National Park (Eyri National Park).
17	Improve the visual and sensory and landscape habitat value of the forest by increasing native woodland along the Hirnant and Glyn Valleys.
18	Maintain existing routes and recreation facilities in the forest.
19	Maintain and improve opportunities for continued use of forest roads and public rights of way including other tracks and paths within the forest, for walkers, cyclists and horse riders.
20	Maintain Public Rights of Way affected by planned harvesting operations including, felling, thinning and restocking.
21	Explore opportunities for working together with adjoining landowners, stakeholders and on projects such as the 'Dee LIFE project' to develop priorities and plans which will improve the connectivity and long-term resilience of ecosystems in the wider landscape.
22	Continue to explore the potential for small scale hydro projects such as in Cwm-Hesgen.

2. Methodology

2.1 Overview

In order to develop sustainable geomorphological and ecological functioning throughout Aberhirnant Forest, any restoration options must recognise, understand and utilise the interlinkages between river/drainage channel form, function and ecology. A spatially integrated study has been conducted to gain the understanding necessary to describe system form and behaviour and focus efforts on recovering and increasing the resilience of the riverine and water environment within Aberhirnant Forest by restoring natural features and function. This study combines desk-based and targeted field-based components, to deliver the geomorphological analysis and ecological interpretation of the physical impacts on Aberhirnant Forest.

2.2 Desk-based assessment

The desk-based component involved reviewing a wide range of information provided for this study to investigate both the historic and natural environment. The supplied information has been summarised in Appendix A. In addition, other sources openly available through the internet (e.g. LiDAR DTM, historical maps, geology and soils, WFD) have been utilised. The review and incorporation of this information is essential to understand the wider context of the study area and its headwater streams. This enables identification of local and forest-wide controls that may be influencing geomorphic processes and ecological functioning within Aberhirnant Forest.

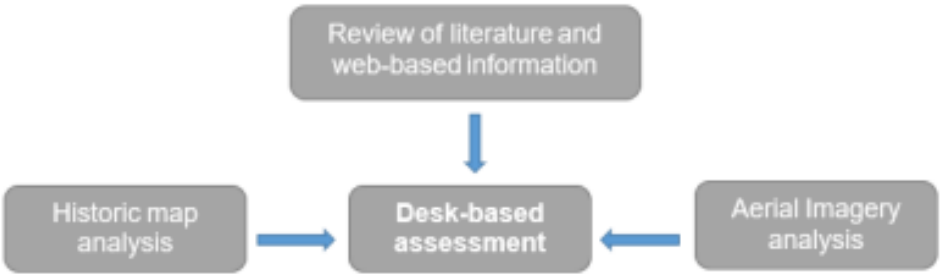

Figure 2-1: Desk-based assessment of a study area

2.3 Flow Accumulator tool

To help identify drainage channels and preferential flow pathways throughout the site for the Drainage Plan and Water Management Strategy, a flow accumulation analysis was undertaken using the 1m bare earth LiDAR DTM and the Flow Accumulation (Spatial Analyst) tool in ArcMaps. The tool calculates the quantity of flow that passes into each downslope cell. It requires a Flow Direction Raster to be generated before the final Flow Accumulation raster. High flow accumulation areas, i.e. concentrated flow, can be used to identify the drainage channels and preferential flow pathways. Figure 2-2 shows that there are many potential flow pathways across the study area, some being artificially modified due to, for example, roads/tracks within the DTM.

As LiDAR does not penetrate vegetation in densely covered areas well, such as in Aberhirnant Forest, the underlying land surface topography may not have been accurately picked up. As a result, the output raster generated by the Flow Accumulator Tool (that uses the available bare earth LiDAR Digital Terrain Model) may not be representative of all true drainage channel locations, hence why ground truthing is required. It is also important to note that the Flow Accumulation Tool may identify drainage channels in areas where flow is not present. This is likely to occur in areas of depression within the LiDAR DTM as the quantity of flow that passes into each downslope cell is calculated.

For the purposes of planning the site visit during which drainage channel locations would be ground truthed, a Watershed (Spatial Analyst) Tool in ArcMaps was run using the Flow Direction Raster (generated from the Flow Accumulation Tool run) in order to delineate the sub-catchment boundaries within the study area and to inform site assessments. The tool uses a point shapefile input at the location of the watercourse/stream where a sub-catchment boundary is required and the Flow Direction Raster. Five sub-catchment boundaries were derived across the Aberhirnant forest using this method (see Figure 2-3).

The tool only creates a sub-catchment boundary line for watercourses that are picked up in the initial Flow Direction Raster. Whether a watercourse is recognised during the raster creation is likely due to the size of the stream and the total weighting of cells. As a result, some watercourses that can be observed in present-day OS mapping may have not been picked up in the raster, therefore preventing the accurate delineation of a sub-catchment boundary for particular streams. This limitation did restrict the number of boundaries derived across Aberhirnant Forest.

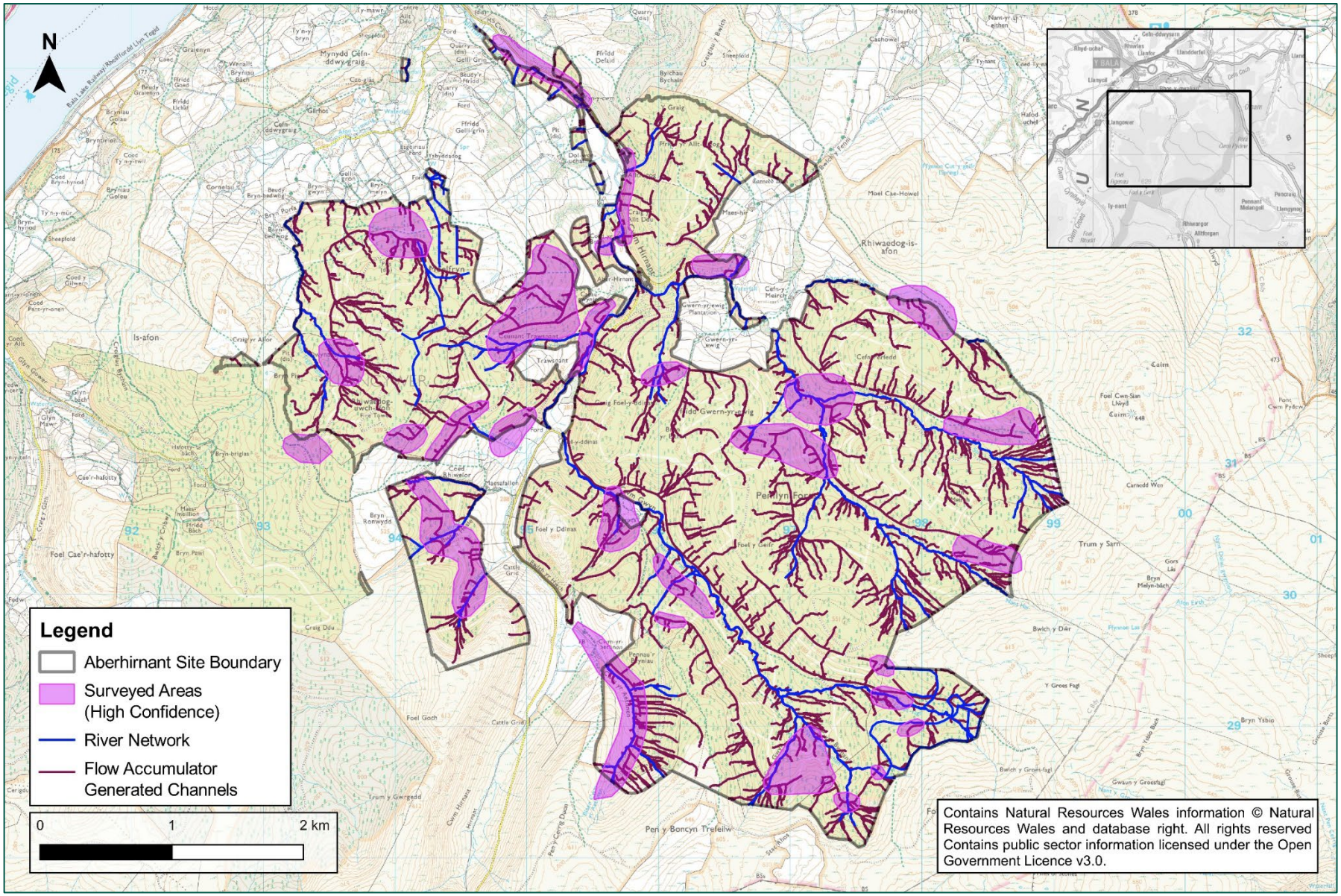

Figure 2-2: Aberhirnant drainage map

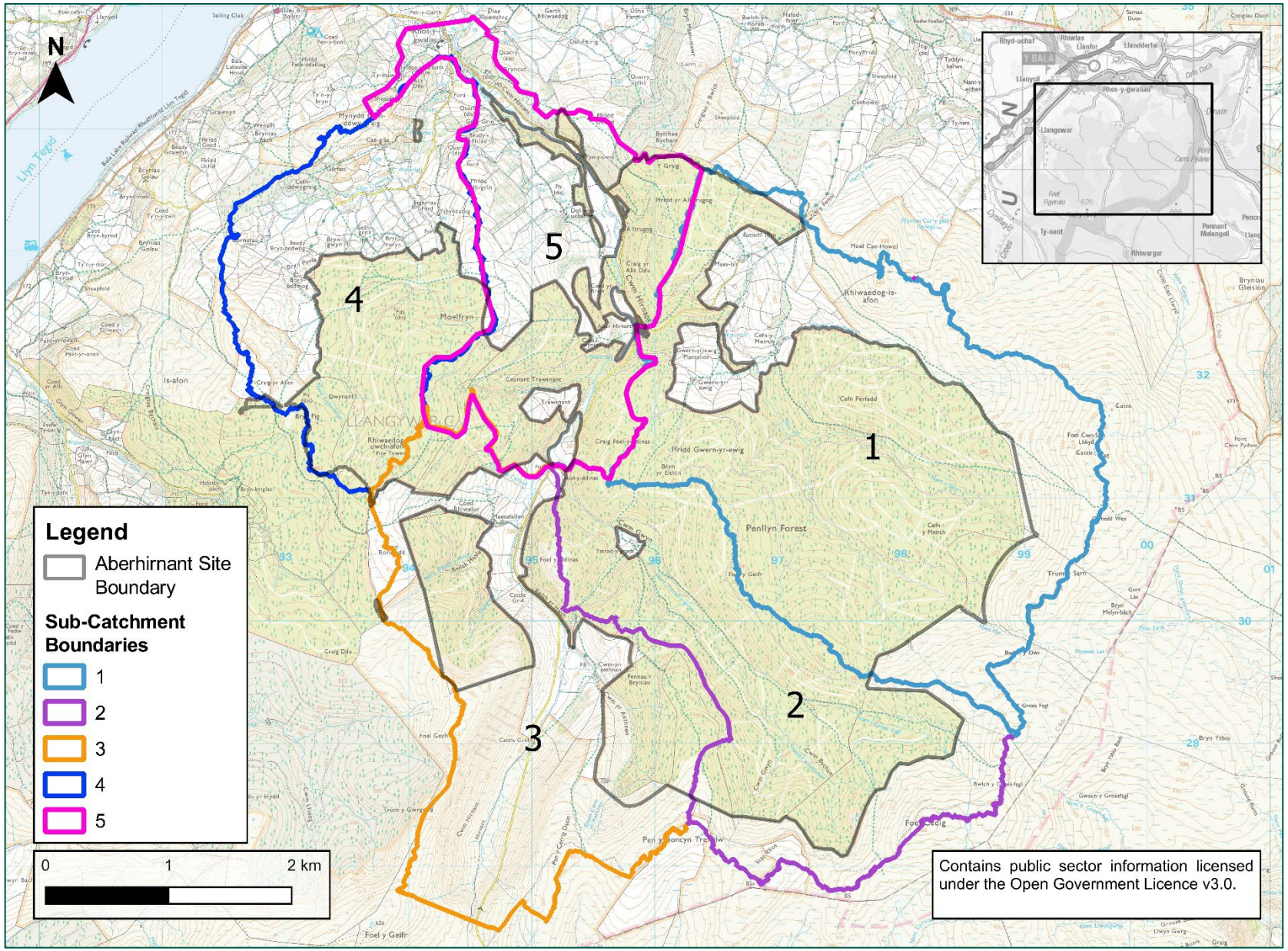

Figure 2-3: Aberhirnant Forest sub-catchment boundaries

2.4 Inventory list

An inventory list was also created prior to the site visit. The aim of the list was to help categorise site observations into different feature types, such as Forest Roads, Watercourses, Riparian Zone and Forest Drains. These feature types were selected as they were considered important to inform the development of the Water Management Strategy and Drainage Plan.

Once a feature type was selected, the list revealed a detailed set of questions/prompts to help guide and record important primary data regarding the characteristics of the location (point/area) in question, together with potential NFM opportunities that could be documented in the WMS. After consultation with NRW, this list was refined, finalised and the template uploaded to the tablet based GISMapp tool for use during the site walkover (see Appendix A). After the site visit to Tarenig, the inventory list was adapted to include a text box to log open ground and natural contour overland flow pathway observations.

GISMapp Tool is an IOS-based mobile data capture tool that allowed full data capture of geolocated photographs and spatial data on the iPad in the field. The data was then synchronised in real time using the mobile phone network, allowing data and notes collected in the field to be uploaded instantly, ensuring no data loss.

The inventory list was valuable on site to help steer observations and prompt the recording of large amounts of data. However, as the list was so extensive and to conserve time, it was not practical to complete for every spot check location where a change in geomorphic or ecological characteristics was identified. The degree of completeness of the inventory (and therefore the level of detail) for each geographic point/area in the inventory list increased at locations where there were possibilities to deliver multiple benefits (i.e. NFM, water quality/sediment, ecology) were present and at locations where there were clearly more significant pressures taking place that needed to be addressed. Many photos were taken, especially at these ‘prime’ sites, to provide more visual context.

To rectify this, a simplified inventory list has been created for use at other forest management locations, locations that don’t include the trial WMS sites (see Appendix B). This list still ensures that sufficient information is recorded.

Also, the template did not accommodate for some features such as observed overland flow pathways that followed natural hill contours or open ground. Therefore, this should be added to the template if used at other forest management sites.

2.5 Geomorphological walkover and ecological survey

The targeted field-based component of the study comprises JBA's bespoke Integrated Riparian Survey (IRiS) methodology, which combines a geomorphological and ecological walkover of the study area. The geomorphologist records physical features of the river channel network (both natural and artificial channels, such as forest or road-side drains), their riparian strip, and (if present) associated floodplain. The ecologist made general observations at each stopping point, including the potential for any protected species including for fish species listed on the Environment (Wales) Act Section 7 list and observations of ecological habitat based upon the UKHab classification system. Observations of land cover and general condition of open ground areas were also made, given their potential to impact the river network and to support integrated catchment management interventions. Together, a detailed understanding of the functioning of the system and how this influences eco-geomorphology throughout the study area is developed.

A site walkover was conducted by JBA Consulting over the period 29th January 2024 to 2nd February 2024 to record geomorphic and ecological features, ground truth the identified drainage channel locations and to assess the potential for NFM opportunities within priority areas predetermined by NRW. These included the following:

- Riparian woodland
- Forestry coupes (felling between 2017-2034)
- Natural Reserves
- Major bridges/culverts
- Open Ground
- Watercourses

To ensure sufficient coverage of the priority areas throughout Aberhirnant Forest, a certain number of sub-catchments (delineated using the Watershed Tool pre-site visit) were visited each day. A handheld clinometer was used to site to measure the gradient of the watercourses (see Section 4.2). Figure 2-4 shows the priority areas within Aberhirnant Forest as well as the extent of the walkover via site photo locations.

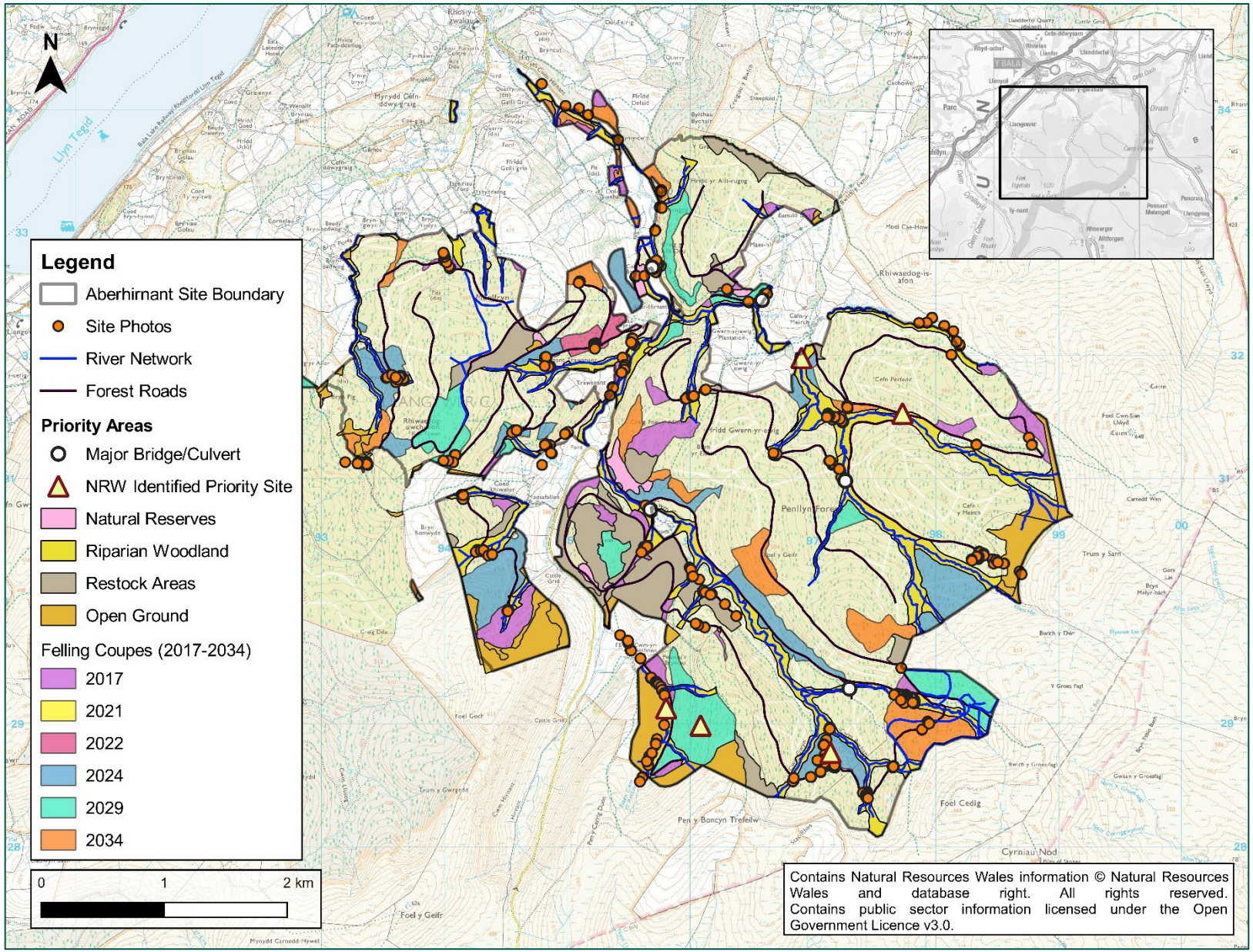

Figure 2-4: Priority areas within Aberhirnant Forest

2.6 Identification of key pressures and options

An assessment of morphological and ecological character was undertaken for the catchment, based on a combination of data collected during site walkovers and desk-based research. Following the assessment, the key pressures influencing the morphology and ecology of the catchment were identified and options (including natural flood management and river restoration) to mitigate or eliminate these pressures have been recommended. The key pressures identified across the catchment are summarised in Section 5. The potential natural flood management and restoration options are presented in Section 7. The key geomorphological and ecological characteristics are summarised, and the key pressures and restoration options are listed. In addition, the restoration options are also visualised in a series of maps.

2.7 Implementation of the delivery plan

Implementation of integrated catchment management opportunities within Aberhirnant Forest must be a collaborative process. Evidence from this report should be combined with local knowledge (especially with respect to forestry operations and management) and new information and research, as they come to light.

3. Study area baseline

3.1 Study area topography

The Aberhirnant Forest topography is shown in Figure 3-1, using 1m resolution LiDAR DTM. Aberhirnant Forest is situated to the southeast of Bala Lake, within Eyri National Park and covers an area of approximately 1,736 ha (17.36km^2). The forest extends over two river catchments; the Hirnant which flows to the River Dee, and the River Glyn which flows west to Bala Lake. The River Dee catchment covers an area of approximately 2,251km^2 (Natural Resources Wales, n.d.p) and the River Glyn catchment covers an area of approximately 129.5km^2 (Natural Resources Wales, 2024).

The topography of the forest varies between upland areas and valleys formed by the Berwyn Mountain Range. The forests western and eastern upland areas are separated by Cwm Hirnant which carries the Hirnant from Foel y Geifr, Foel y Garnedd and Pen Bryn-y-fawnog mountains through the central areas of the forest to the River Dee. The Hirnant is fed by several tributaries and smaller headwater streams that run through western and eastern areas of the forest.

Within the western areas, the forest is situated on the upland areas of Frîdd Gelli-Grin, Bryn Pig and Rhiwaedog-uwch-afon. Small headwater streams are found either side of these mountains, such as the Nant Figyn-felen which flows along the western boundary to Afon Cymerig. The Dallgwm, Nant Bŵlch-y-ffosle, Ceunant Cylliod and Nant Rhiw-y-llyn, flow down the eastern side to the Hirnant. These headwater streams are confined to a straight channel planform due to steep channel gradients and channel incision.

Within the eastern areas of the forest, there are two distinctive valleys formed between Y Graig, Craig Foel y-ddinas and Foel y ddinas. The northeastern valley carries the Nant Hir,

which drains water from the hillsides of Foel Cwm-Sian Llywd, Carnedd Wen and Trum y Sarn. The southeastern valley known as Cwn Gwyn funnels several headwater streams from the mountains; Y Groes Fagl, Foel Cedig and Stac Rhos into the Nant Ystrad-y-groes watercourse.

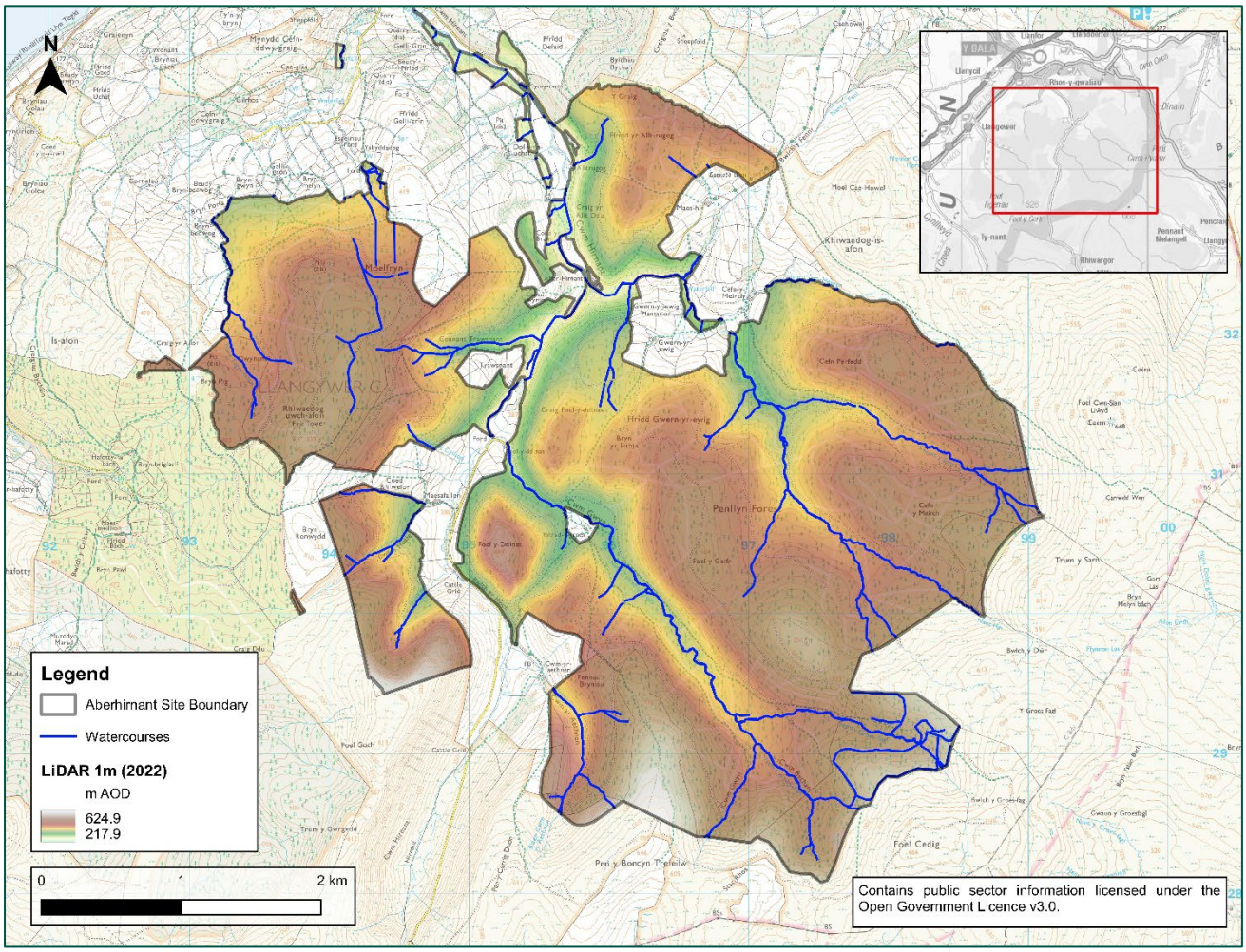

Figure 3-1: Topography within Aberhirnant Forest

3.2 Bedrock geology

The bedrock geology of the Aberhirnant Forest study area is displayed in Figure 3-2. (data from British Geological Survey, 2023). Aberhirnant forest is underlain by a variety of bedrock types.

Along the north western extents of the forest, near Bryn-bedwog, Rhos-y-gwaliau, Craig yr Allor and the headwaters of Afon Cymerig, the forest is underlain by the Ceiswyn Formation comprised of silty-mudstones and siltstones with subordinate sandstones and tuffs. These sedimentary rocks are shallow-marine origin and formed between 457.5 and 452.75 million years ago during the Ordovician period.

Adjoining this bedrock to the east is a thin band of Gelli-Grin Calcerous Ash Formation which spans from Bryncut and Gelli-Grin, through the Aberhirnant Forest to the locations of

Craig yr Allor and Bryn Pig along the western boundary of the study area. These igneous rocks are volcanic (extrusive) and comprise of calcareous volcaniclastic sandstone and tuff formed between 454 and 452.1 million years ago during the Ordovician period. Within this bedrock band, a small swathe of Cymerig Limestone Member comprising of limestones, mudstones and biogenic carbonate material is found in the western area of Aberhirnant Forest. This bedrock formed during the same Ordovician period, between 452.75 and 453.1 million years ago.

Within the central-western areas of the forest, Moelfryn Mudstone Formation comprising of mudstones, siltstone, localised sandstone and limestone beds underlain areas around Ffrîdd Defaid, Dol-wen-uchaf, Alltrugog, Craig yr Allt Ddu, Aber-Hirnant, Moelfryn, Rhiwaedog-uwch-afon and Maesafallen. These sedimentary rocks are marine in origin and formed between 449 and 443.8 million years ago during the Ordovician period.

Throughout the central areas of the forest, three distinctive bands of bedrock are found. Adjacent to the Moelfryn Mudstone formation is the Foel Y Ddinas Mudstone Formation, which runs from the northern forest boundary near Y Graig, south through Craig Foel-y-ddinas and Foel y-Ddinas to the southern boundary along the eastern slopes of Foel Goch. These sedimentary bedrocks comprise of silty mudstones with quartzite and limestone. This formation formed between 445.2 and 443.8 million years ago during the Ordovician period.

The central band of bedrock consists of the Cwm Yr Aethnen Mudstone formation. This begins at the northern forest boundary and passes through central areas of Gwern-yr-ewig plantation and Ystrad-y-groes, to Cwm-yr-aethnen, located at the southern boundary of Aberhirnant Forest. This bedrock comprises of mudstone-dominated turbidite sediment which are detrital and structured with coarse to fine-grained minerals. These sedimentary rocks are marine in origin and formed between 443.8 and 433.4 million years ago during the Silurian period.

The third central band which passes through Maes-hîr, Gwern-yr-ewig, Ffrîdd Gwern-yr-ewig to Cwm-yr-aethnen on the southern boundary is the Dolgau mudstone formation. This comprises of coarse to fine-grained mudstones with turbidite sediments. These sedimentary rocks are marine in origin and were also formed between 443.8 and 433.4 million years ago during the Silurian period.

The eastern half of Aberhirnant Forest is underlain by Penstrowed Grits Formation. This comprises of mudstones with greywacke sandstones and turbidite sediments which are of marine origin. This bedrock ranges between medium to coarse grained sediments and was formed between 433.4 and 430.5 million years ago during the Silurian period.

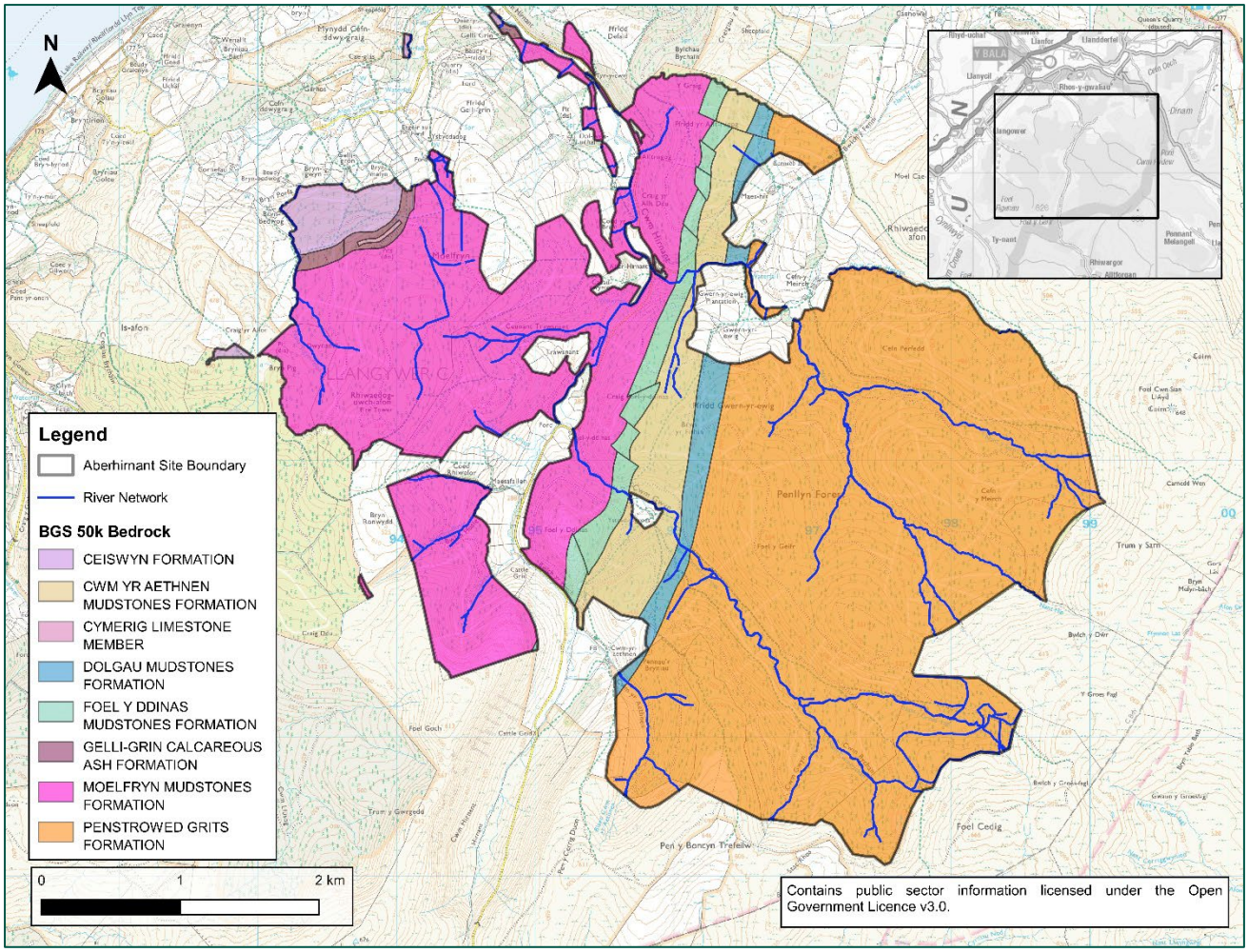

Figure 3-2: Bedrock geology within Aberhirnant Forest

3.3 Superficial geology

The superficial geology of the Aberhirnant Forest is displayed in Figure 3-3 (British Geological Survey, 2023). There is a variety of superficial deposits within the Aberhirnant Forest; mostly within the vicinity of the Hirnant, Nant Hir and Nant Ystrad-y-groes. There are some superficial deposits located along headwater streams; however, there are large areas where there are no superficial deposits/no information recorded.

Quaternary sedimentary superficial deposits with varying texture, structure and composition underly the upland forest areas of Moelfryn and Bryn Pig, located in the western areas of the forest. Quaternary superficial deposits of Head – clay, silt, sand and gravel underlain the western Cwm Hirnant slopes and around the base of the Foel y Ddinas.

Within the basin of Cwm Hirnant, superficial deposits of Till Devenisan - diamicton (unsorted sediment with gravel in fine mud matrix) are found on the lower slopes. Adjacent to the Hirnant, particularly in the central and lower reaches of the watercourse, Alluvium – clay, silt, sand and gravel are found with peat in some places. These sediments are detrital and range between fine to coarse grained deposits. These form the present-day floodplain.

The slopes of Foel Cwm-Sian Llywd, Carnedd Wen, Trum y Sarn, Y Groes Fagl, Foel Cedig and Stac Rhos along the eastern boundary of the forest are underlain by peat deposits. Within the forests eastern areas, Quaternary superficial deposits of Head – clay, silt, sand and gravel underlain the upper slopes of the Nant Hir valley and Cwm Gwyn. Along the base of both valleys, superficial deposits of Till Devenisan – Diamicton (unsorted sediment with gravel in fine mud matrix) are found.

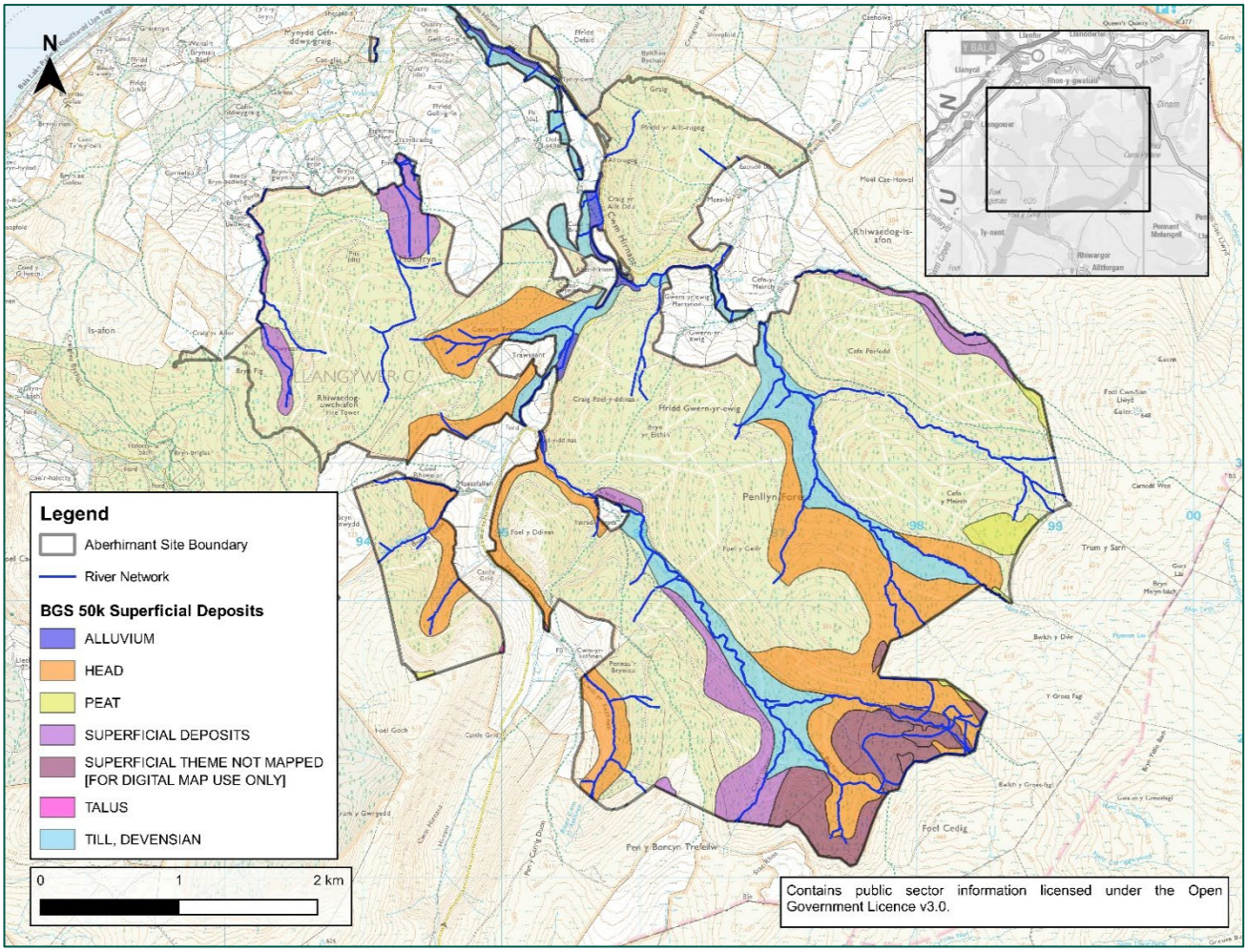

Figure 3-3: Superficial deposits within Aberhirnant Forest

3.4 Soil characteristics

Throughout the Aberhirnant Forest, various soil properties ranging from loamy and clayey soils to peatlands are found. According to the Land Information System (LandIS) developed by Cranfield Environment Centre (CEC), the headwater streams located in the western areas; flowing from the upland areas of Bryn Pig and Rhiwaedog-uwch-afon flow over acidic loamy permeable soils over rock, which have a wet peaty surface horizon and bleached subsurface horizon, often with thin ironpan (0654a HAFREN). Within these soils, water is held in the surface horizons and the peat acts as a sponge, forming seasonally waterlogged soils even though the subsoils drain freely.

Towards Moelfryn and the Cymerig Afon, these soils change to acidic fine silty, loamy and clayey soils which are slowly permeable and seasonally waterlogged with wet peaty horizons (0713d CEGIN, 0713e BRICKFIELD 1). In wet regions CEGIN and BRICKFIELD soils remain waterlogged for long periods in the growing season.

The headwater streams draining into the Hirnant, throughout the Cwm Hirnant and along the Nant-y-strad-groes watercourse are characterised as well drained fine loamy or silty soils over rock (0611c MONOD). Although these soils are permeable and well drained, the climate keeps them moist throughout the year. These soils readily absorb winter rainfall except on steep land or where bedrock is near to the surface.

The Nant Y Sarn and Nant Hir are also underlain by acidic loamy upland soils with wet peaty surface (0654a HAFREN). Upstream of these, the headwater streams which flow from the hillsides of Foel Cwm-Sian Llywd, Carnedd Wen, Trum y Sarn, Y Groes Fagl, Foel Cedig and Stac Rhos are classified as blanket bog peat soils, which are thick naturally wet - acidic peat soils (1013b CROWDY 2). These soils are vulnerable to erosion, especially in areas where the ground is exposed from vegetation loss.

Peatland is present in areas of the upland forest areas (see Figure 3-4) (DataMapWales, 2022). These locations will have a significant amount of organic matter, be frequently inundated and be dominated by sphagnum mosses. The understorey of the dense areas of forestry plantation is dominated by bryophytes, including sphagnum species. In drier areas, Heather *Calluna vulgaris* and Bilberry *Vaccinium myrtillus* are present with Soft Rush *Juncus effusus* dominating the wetter areas and Birch *Betula* sp. and Willow *Salix* sp. developing along the watercourse channels where gaps in the plantation are present. Bracken *Pteridium aquilinum* is present on the upland areas adjacent to the forest boundary. Stands of Rhododendron *Rhododendron ponticum* are present throughout the forest.

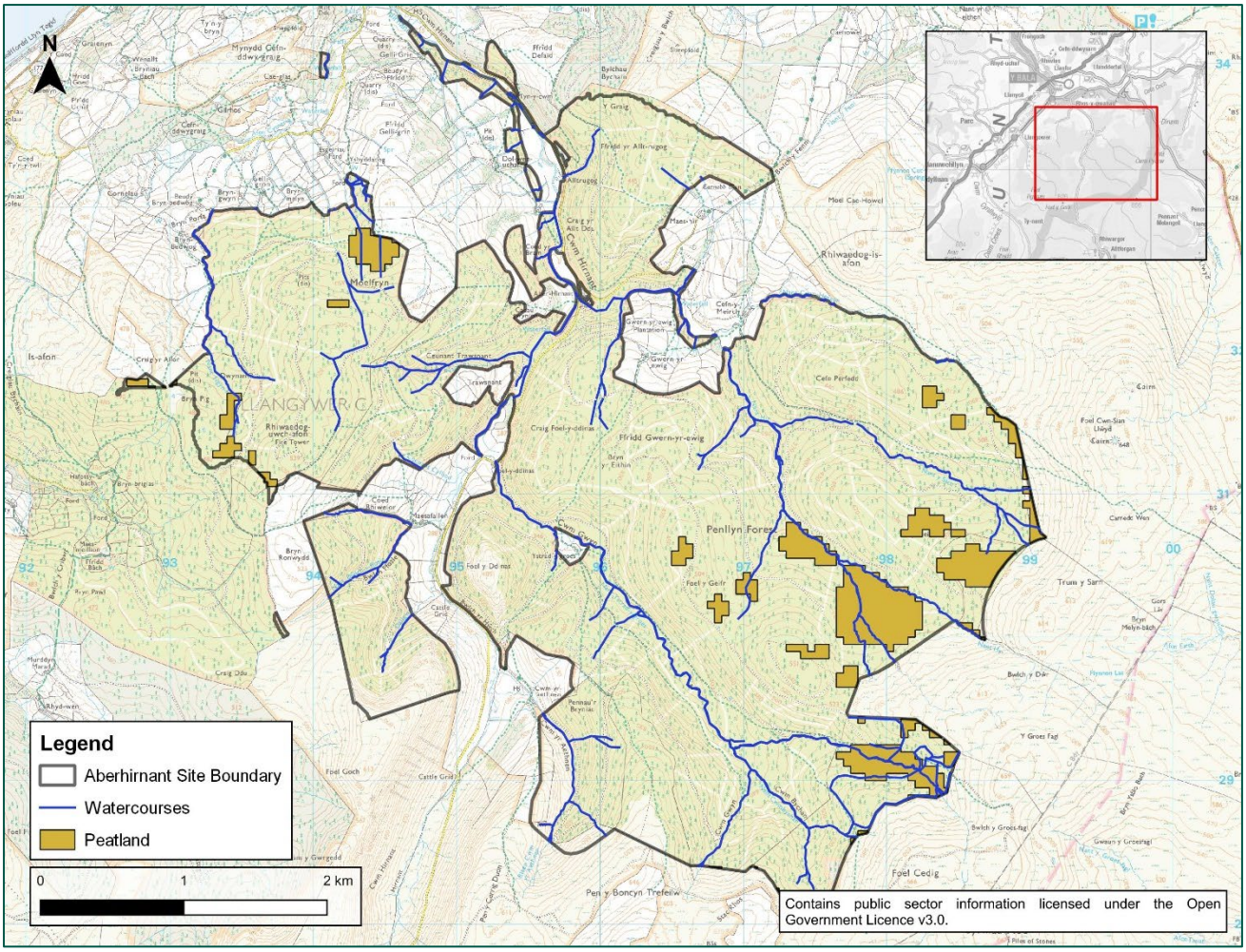

Figure 3-4: Peatland across Aberhirnant Forest study area

3.5 Land cover

In general, the majority of the land cover within the Aberhirnant Forest boundary comprises of woodland (~65%), followed by grasslands (~15%) and mountain/heath/bog areas (~19.5%). Due to the terrain, arable/horticultural and urbanised areas are limited (see Figure 3-5).

More specifically, within the western upland areas of the forest, round Bryn Pig and Rhiwaedog-uwch-afon, the land cover is predominantly coniferous with cleared moorland generating bog habitats in wetter parts.

To the north of these areas near to Moelfryn, the forest is still coniferous; however, on the southern slopes of Fridd Gelli-Grin the forest has been cleared and is largely grassland. The habitats within this area are seasonally wet pastures and woodlands.

Along the Cwm Hirnant and lower areas of Cwm Gwyn (Nant-y-strad-groes watercourse) the majority of the land is open ground comprising of grasslands and moorlands. There is also a mixture of deciduous and coniferous woodlands located on the floodplains of the Hirnant and Nant-y-strad-groes.

Upstream of the lower areas of the Cwm Gwyn, the valley progresses into more coniferous forest. At the hillslopes of Foel Cwm-Sian Llywd, Carnedd Wen, Trum y Sarn, Y Groes Fagl, Foel Cedig and Stac Rhos, the land cover is characterised as open moorland and grassland. Habitats here are generally wet heather moor with flush and bog communities.

Within northeastern areas of the forest along Nant Y Sarn and Nant Hir, the valleys are largely forested with conifers, while upland areas such as those around Cefn y Meirch have been recently cleared leaving open ground. Downstream of these watercourses towards the Hirnant, the landcover comprises of a mixture between grasslands, moorlands and woodlands.

Priority Area Forestry Coupes between 2017-2034, provided by NRW, cover approximately 37% of the total Aberhirnant Forest area.

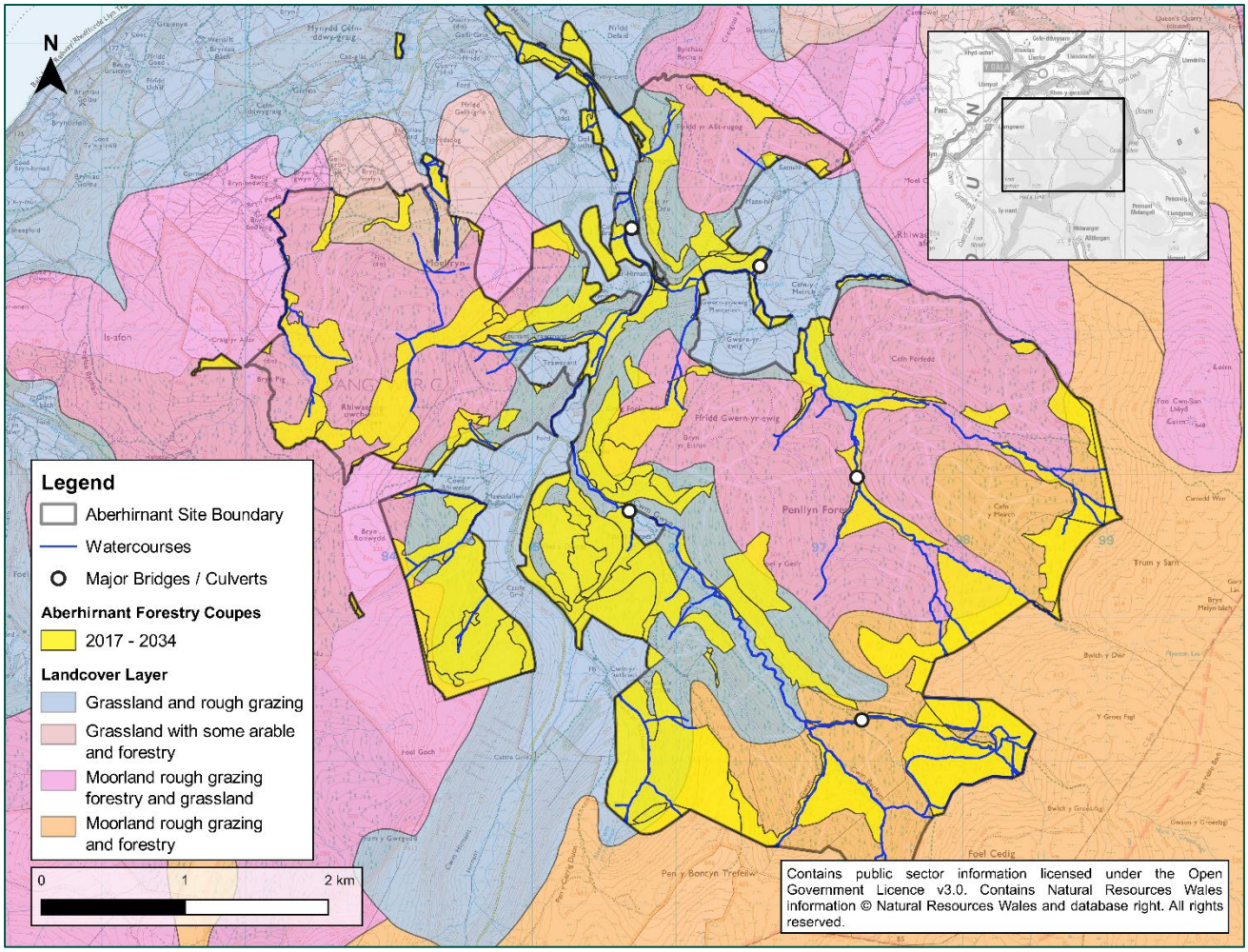

Figure 3-5: Land cover across Aberhirnant Forest study area

3.6 Hydrology and flow regime

No gauging stations were identified along any of the headwater streams within Aberhirnant Forest. Consequently, the hydrological analysis of the watercourses is based upon the catchment characteristics. Due to the terrain and impermeable bedrock geology of the forest, it is likely that the headwater streams have a flashy response to rainfall events. LIDAR DTM analysis reveals that all headwater streams flow down steep, narrow valleys that confine water to the channel, which ultimately leads to high flow velocities.

Rapid runoff is further exacerbated by land use practices within the forest that will have resulted in the creation of many artificial drainage channels and linear depressions with the aim of directing water downslope from the conifer plantations. During the onset of rainfall, discharge rates along the Hirnant, Nant Hir, Nant Ystrad-y-groes, Glyn and Afon Cymerig are likely to be high, leading to a fast rise to peak.

3.7 Fluvial flood risk

The Fluvial Flood Zones 2 and 3 across Aberhirnant Forest are presented in Figure 3-6. Flood Zone 2 areas have between 1% and 0.1% annual probability of fluvial flooding including an allowance for climate change. Flood Zone 3 areas have a 1% or greater annual probability of fluvial flooding, including an allowance for climate change. Flood zone definitions and shapefiles have been obtained from DataMapWales (DataMapWales, 2023). Climate change information is included within the Flood Map for Planning to show how flood risk will affect river over the next 100 years.

Aberhirnant Forest is mostly within Flood Zone 1; however, the majority of the headwater streams are excluded from the Flood Map for Planning due to their size. Flood zones are therefore only visible along main rivers and streams such as the Hirnant, Nant Hir and Nant Ystrad-y-groes.

The Hirnant rises at the foot of the Foel y geifr, Foel y Garnedd and Pen Bryn-y-fawnog mountains and flows north through a sloped valley towards the Aberhirnant Forest. Flood Zones 2 and 3 become visible nearby the central southern forest boundary at the confluence with Blaen Cwm yr Aethnen. From here, the Hirnant flows around the western side of Foel y Ddinas. At these locations the flood zones are confined to the western valley side and the access road to the east of the river.

At the confluence with Nant Ystrad-y-groes, the Hirnant flows into the Aberhirnant Forest. At this location, areas of Flood Zone 3 are visible across the access road and along the forest boundary. As the Hirnant continues to flow north through the centre of forest, the watercourse is classified as Flood Zone 3. At Aberhirnant Hall, where the Hirnant confluences with Nant Hir, areas of Flood Zone 2 and 3 are visible along the forest boundary and across the access road. Between this location and the confluence of the Afon Cymarig at Rhos-y-gwaliau, areas within the forest and access road are within Flood Zone 2 and 3.

Within southern central areas of the Aberhirnant Forest, areas of Flood Zone 2 and 3 are also visible along the Nant Ystrad-y-groes. This river is fed by smaller headwater streams such as the Cwm gwyn, Nant Cwmbychan and Nant y Groes-fagl which convey water from the Stac Rhos, Cefn Gwyntog, Foel Cedig and Y Groes Fagl mountains.

Areas of Flood Zone 2 and 3 are also found in the northern area of the Aberhirnant Forest, along Nant Hir. This stream is formed from the headwater streams found in the upland areas of Y Groes Fagl, Trum y Sarn, Carnedd Wen and Foel Cwn Sian Llwyd. Similar to other locations, the water is confined by steep topography. Further downstream, adjacent to Gwern-yr-ewig Plantation, areas of Flood Zone 3 cross over the boundary of Aberhirnant Forest.

Flooding is confined to the Afon Hirnant downstream of Aberhirnant Forest until its confluence with the River Dee, located approximately 3km away. The nearest town with a significant fluvial flood risk is Corwen. About 20km downstream of the Hirnant-Dee confluence.

There are no flood defences within the vicinity of Aberhirnant Forest.

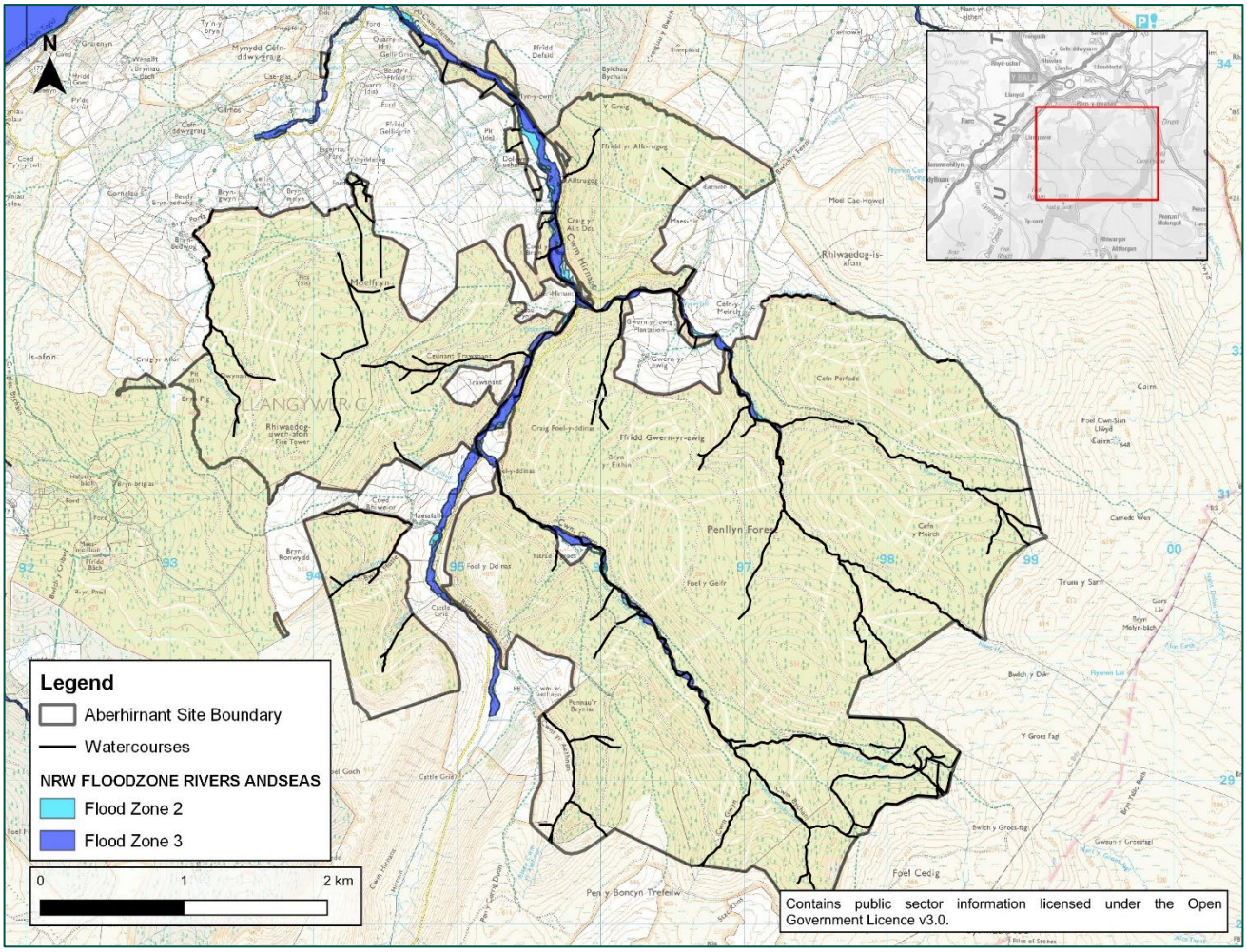

Figure 3-6: Flood Zones within the vicinity of Aberhirnant Forest

3.8 Surface water flood risk

Areas at risk of surface water flooding are shown in Figure 3-7 below. Areas at high risk of surface water flooding are largely confined to the headwater streams that run through Aberhirnant Forest. High surface water flood risk can also be observed between headwater streams located in the east of the study area, such as the Nant Mir and Nant y Sarn.

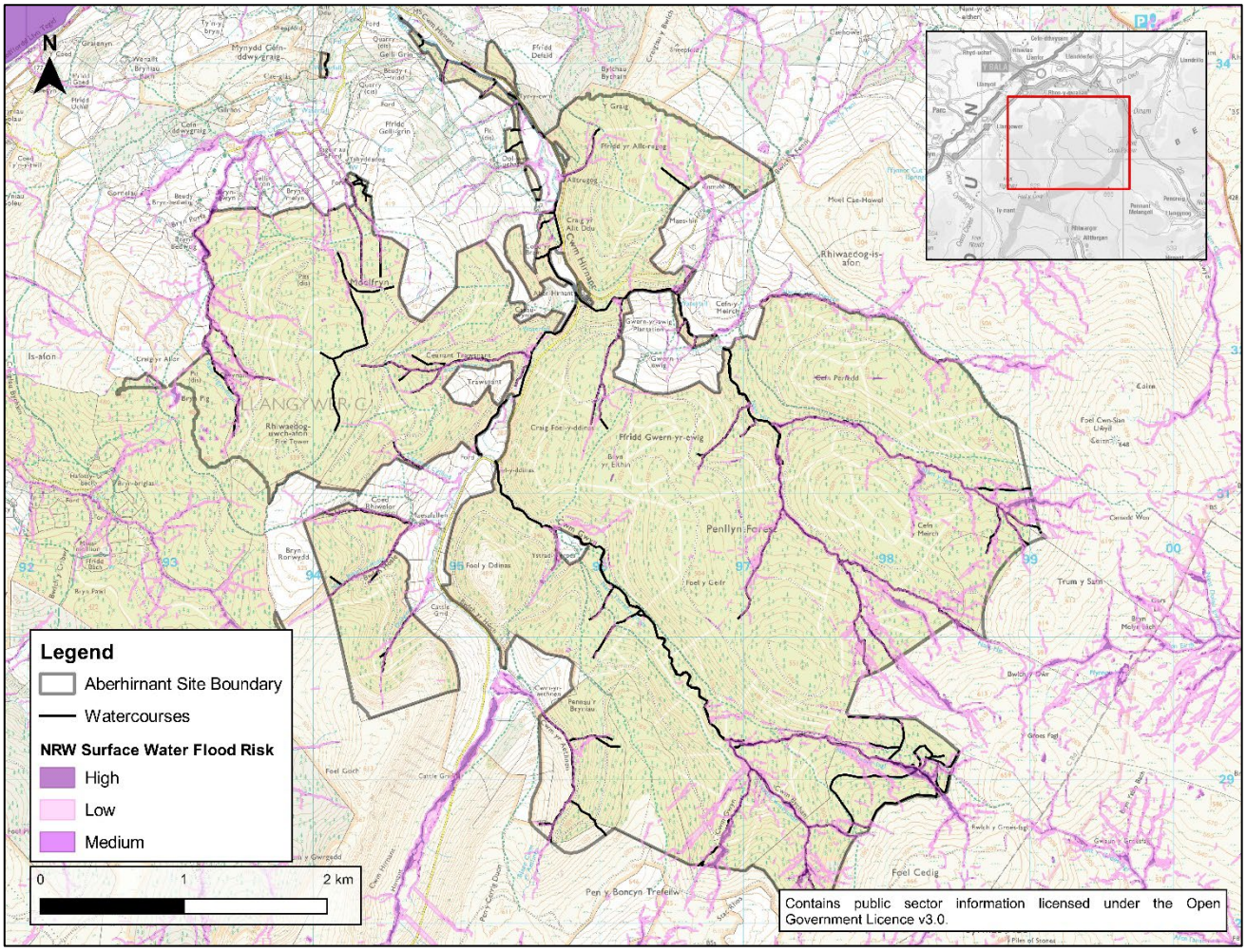

Figure 3-7: Surface water flood risk within Aberhirnant Forest

3.9 Water Framework Directive

The headwater streams within Aberhirnant Forest are located within the Dee Management Catchment which is situated within the Dee River Basin District (RBD) and is covered by its associated River Basin Management Plan (RBMP). The Aberhirnant Forest drains into two Water Framework Directive (WFD) waterbody catchments named Hirnant and Glyn. The overall WFD status during Cycle 3 (2021) range between 'Moderate' to 'Good'.

All information is sourced from the Water Watch Wales website (Water Watch Wales, 2022). The status of each WFD waterbody is presented in Table 3-1.

Table 3-1: Current status of WFD waterbodies within Aberhirnant Forest

Water body ID	Name of water body	Hydromorphological designation	Current overall status / potential
GB111067051860	Hirnant	Natural / Not designated as a heavily modified water body (HMWB)	Good
GB111067051820	Glyn	Natural / Not designated as a heavily modified water body (HMWB)	Moderate

3.9.1 Hirnant

The current overall status of the 'Hirnant' waterbody (ID: GB111067051860) is identified as 'Good' (2021 Cycle 3). The waterbody is classified as natural. The overall status objective for the waterbody is to reach 'Good' by 2027. The classification for fish in the river is 'High' (2021 Cycle 3). Data from electrofishing surveys has recorded Atlantic Salmon, Trout, Stone Loach, Minnow, European Eel and Stickleback in the river.

3.9.2 Glyn

The current overall status of the 'Glyn' waterbody (ID: GB111067051820) is identified as 'Moderate' (2021 Cycle 3). The waterbody is classified as natural. The overall status objective of the waterbody is to reach 'Good' by 2027 (Lower Confidence - Default). The reasons why this waterbody is not achieving a 'Good' overall status are listed below:

- Low flow associated with impoundment – no water storage, impacting fish.
- Physical modification (Flood protection structures) creating barriers to fish migration.

3.10 Environmental desk-based assessment

3.10.1 Designated sites

Aberhirnant Forest is a large site, approximately 1700ha and lies in two river catchments, with the Hirnant River and associated tributaries flowing through the forestry connecting to the River Dee approximately 3km downstream. The site is located within Eryri National Park and is adjacent to the following designated sites:

- Berwyn SSSI
- Berwyn and South Clwyd Mountains SAC
- Berwyn SPA

In addition, the site is hydrologically connected or in close proximity to:

- Llyn Tegid SSSI /Ramsar
- River Dee and Bala Lake SAC
- Chwarel Cwm Hirnant SSSI
- Chwarel Gelli-Grin SSSI

Details of the designated sites are provided in the table and figure below.

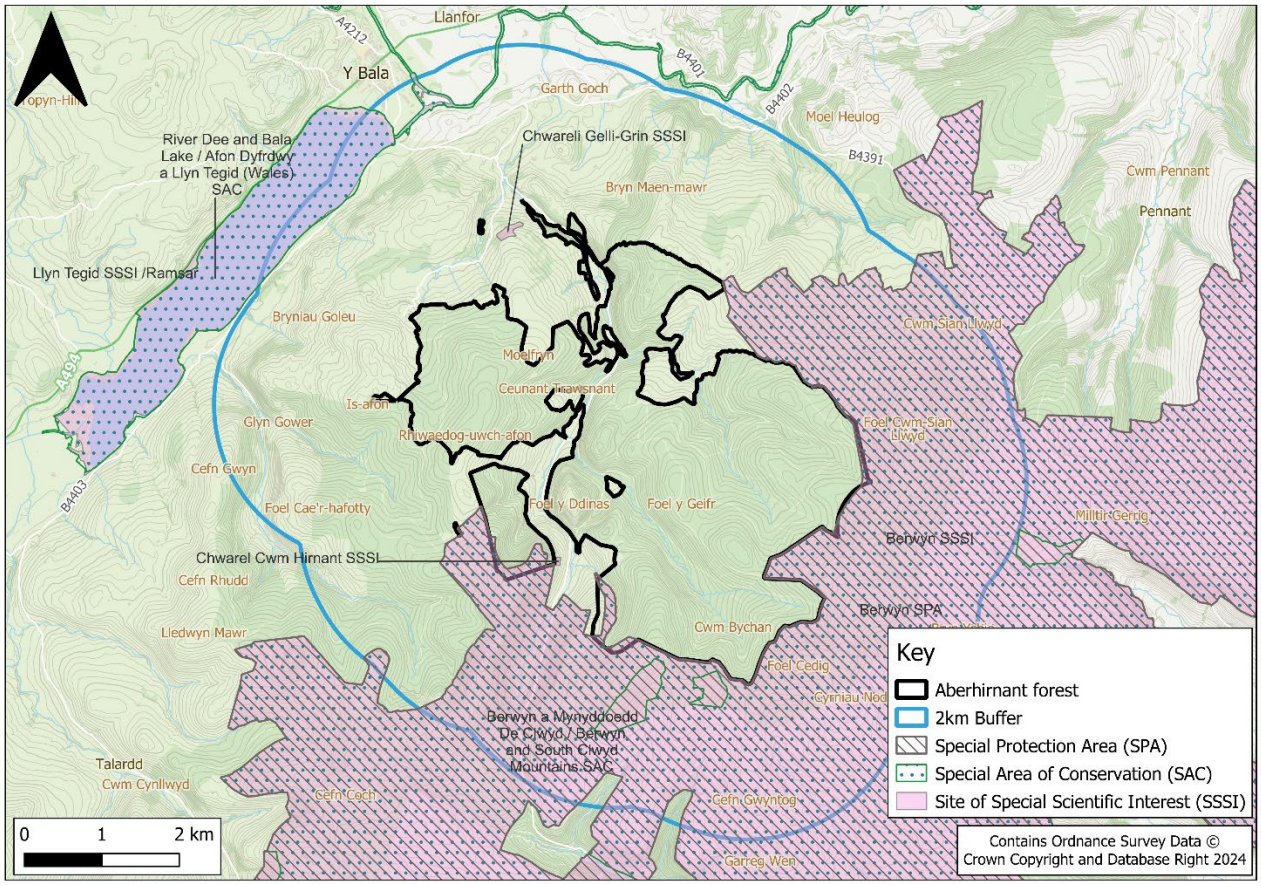

Figure 3-8: Designated sites within 2km of Aberhirnant Forest

Table 3-2: Details of designated sites within 2km of Aberhirnant Forest

Site	Description	Proximity to site
Berwyn and South Clwyd Mountains SAC	The site is a mosaic of habitats and is designated for habitats. The following Annex 1 habitat are a primary reason for selection of this site: • Blanket bogs • European dry heaths The following Annex I habitats are also present as a qualifying feature: • Calcareous and calcshist screes of the montane to alpine levels (*Thlaspietea rotundifolii*) • Calcareous rocky slopes with Chasmophytic vegetation • Semi-natural dry grasslands and scrubland facies: on calcareous substrates (*Festuco-Brometalia*) • Transition mires and quaking bogs	Adjacent to site
Berwyn SSSI	A stretch of moorland, that is of importance for upland breeding birds, blanket mire vegetation and the Welsh Clearwing Moth *Synanthedon scoliaeformis*. The site supports internationally significant numbers of: • Hen harrier *Circus ovaneus* • Merlin *Falco columbarius* • Peregrine *Falco peregrinus* • Red kite *Milvus milvus* The site also supports significant proportions of the Welsh populations of other species including: • Short-eared Owl *Asio flammeus* • Golden Plover *Pluvialis apricaria* • Red Grouse *Lagopus lagopus* • Black grouse *Tetrao tetrix.*	Adjacent to site

Site	Description	Proximity to site
Berwyn SPA	The site supports nationally important breeding populations of four Annex 1 species: • 2-3 pairs of Red Kite (over 1 % of the British population) • 14 pairs of Hen Harrier (over 2% of the British population) • 14 pairs of Merlin (over 2% of the British population); and • 18 pairs of Peregrine (1.5%of the British population). Notable also is the presence of two other Annex 1 species: • Golden Plover • Short-eared owl	Adjacent to site
Chwarel Cwm Hirnant SSSI	The site is comprised of a disused quarry and is considered of international importance for being a biostratigraphical site for its fossil brachiopod assemblage.	Adjacent to site
Chwareli Gelli-Grin SSSI	The site is comprised of natural rock outcrops and a series of disused quarries. The site contains the type locality of the Cymerig Limestone, an important marker horizon which is internationally famous for its brachiopod fauna.	0.1km west
River Dee and Bala Lake SAC	The following Annex 1 habitat are a primary reason for selection of this site: • Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation The following Annex II species are a primary reason for selection of this site: • Atlantic salmon *Salmo salar* • Floating water plantain *Luronium natans* The following Annex II species are present as a qualifying feature, but are not a primary reason for site selection: • Bullhead *Cottus gobio* • River lamprey *Lampetra fluviatilis* • Brook lamprey *Lampetra planeri* • Otter *Lutra lutra* • Sea lamprey *Petromyzon marinus*	1.6km north-west

Site	Description	Proximity to site
Llyn Tegid SSSI /Ramsar	The site is Wales largest natural lake, reaching 42 meters in depth. The site supports invertebrate communities typical of those exposed to oligo-to-mesotrophic lakes. The site supports a range of fish species including Perch, Pike, Roach, Grayling and Gwyniad *Coregonus clapeoides pennantii.*	1.6km north-west

Due to its proximity and connectivity to the sites, the forestry and its management have the potential to impact the sites. The Aberhirnant and Llangower Forest Resource Plan outlines objectives to reduce the impact of forestry operations upon these designated sites. Highlighted actions to be taken include:

- Manage the boundary between the forest and the Berwyn and South Clwyd SAC/SPA for the benefit and favourable condition of dry heath and blanket bog habitats and protected birds including raptors and Black Grouse. Consider different options for management such as native successional woodland buffer zones to minimise the impact of seeding conifers on the SAC.
- Expand the existing riparian woodland network to provide better buffering against harvesting operations and to help improve the water quality in freshwater ecosystems.
- Explore opportunities for working together with adjoining landowners, stakeholders and on projects such as the 'Dee LIFE project' to develop priorities and plans which will improve the connectivity and long-term resilience of ecosystems in the wider landscape.

3.10.2 Protected species

A 5-kilometre (km) buffer area from the study area has been drawn to understand the distribution of species in the wider area. When species in the buffer area are referred to in the report, this includes species recordings within the study area. The recordings from the survey data have been filtered to only include recordings after the year 2000 and within the 5km buffer area.

Key species have been identified by their frequency in the datasets used and, in some cases, their conservation status. These have been identified for each Taxon listed in the report.

Birds

Table 3-3 shows bird species recorded within the 5km buffer period and after the year 2000. Some locations were not available so have not been listed.

Table 3-3: Bird species point data within 5km of Aberhirnant

Common name	Scientific name
Black Grouse	*Lyrurus tetrix*
Black-tailed Godwit	*Limosa limosa*
Brambling	*Fringilla montifringilla*
Common Loon	*Gavia immer*
Cuckoo	*Cuculus canorus*
Eurasian Whimbrel	*Numenius phaeopus*
European Herring Gull	*Larus argentatus*
Goldeneye	*Bucephala clangula*
Grasshopper Warbler	*Locustella naevia*
Kingfisher	*Alcedo atthis*
Little Ringed Plover	*Charadrius dubius*
Merlin	*Falco columbarius*
Nightjar	*Caprimulgus europaeus*
Red Grouse	*Lagopus lagopus*
Song Thrush	*Turdus philomelos*
Turtle Dove	*Streptopelia turtur*
Western Osprey	*Pandion haliaetus*
Whooper Swan	*Cygnus cygnus*
Wood Warbler	*Phylloscopus sibilatrix*

Key species identified in the area are:

- Black grouse, *Lyrurus tetrix*
- Red grouse, *Lagopus lagopus*
- Common Loon, *Gavia immer*
- Cuckoo, *Cuculus canorus*

Black grouse are listed as 'red' in the Red List for Birds of Conservation Concern (2015) and are in decline in the UK. As for the Red Grouse, it is listed as 'green' under the Red List for Birds of Conservation Concern (2021). The main threats towards grouse in general are predation, weather and disease.

Common Loons, also known as Great Northern Divers, are listed as 'amber' under the Red List of Birds of Conservation Concern. Common Loons are rare in the UK, and are normally found breeding in Greenland, Iceland and North America. There are only two recordings of the Common Loon in the 5km buffer area. Both are to the north located close to Llyn Tegid and Coed Rhiwaedog.

The Cuckoo is globally threatened with large declines in breeding populations and population ranges. The cuckoo is rated 'red' under the Red List of Birds of Conservation Concern (2021). Although there is an evident decline of the Cuckoo, the British Trust for Ornithology (BTO) state that 'the reason for this decline is unknown'.

Fish

Electro fishing data

Salmon

Electro fish survey data was provided by NRW. Fishless (F) data entries have been taken out as well as any recordings of '0' Salmon and recordings before 2000. Locations were not available, so the river name has been included.

Table 3-4: Salmon data within 5km of Aberhirnant

Location (River)	Count of 0+ classification (Fry)	Count of >0+ classification (Parr)	Date
Hirnant	10	5	28/06/2006
Hirnant	10	3	16/09/2008
Hirnant	0	0	19/08/2013
Hirnant	40	15	05/07/2004
Hirnant	62	12	05/07/2005

Location (River)	Count of 0+ classification (Fry)	Count of >0+ classification (Parr)	Date
Hirnant	107	11	10/08/2007
Hirnant	53	12	02/07/2008
Hirnant	135	23	01/07/2009
Hirnant	155	9	05/07/2010
Hirnant	57	33	28/07/2011
Hirnant	251	9	15/08/2013
Hirnant	93	17	14/09/2015
Hirnant	254	33	09/08/2016
Hirnant	321	43	18/07/2017
Hirnant	332	52	12/07/2018
Hirnant	89	32	02/07/2019
Hirnant	218	22	03/09/2021
Hirnant	10	5	28/06/2006
Hirnant	10	3	16/09/2008
Hirnant	0	0	19/08/2013
Hirnant	40	15	05/07/2004
Hirnant	62	12	05/07/2005
Hirnant	107	11	10/08/2007
Hirnant	53	12	02/07/2008

Location (River)	Count of 0+ classification (Fry)	Count of >0+ classification (Parr)	Date
Hirnant	135	23	01/07/2009
Hirnant	155	9	05/07/2010
Hirnant	57	33	28/07/2011
Hirnant	251	9	15/08/2013
Hirnant	93	17	14/09/2015
Hirnant	254	33	09/08/2016
Hirnant	321	43	18/07/2017
Hirnant	332	52	12/07/2018
Hirnant	89	32	02/07/2019
Hirnant	218	22	03/09/2021

Trout

Fishless (F) data entries have been taken out as well as any recordings of '0' trout and recordings before 2000. Locations were not available, so the river name has been included.

Table 3-5: Trout data within 5km of Aberhirnant

Location (River)	Count of 0+ classification (Fry)	Count of >0+ classification(Parr)	Date
Hirnant	3	9	28/06/2006
Hirnant	8	1	16/09/2008
Hirnant	34	18	19/08/2013
Hirnant	8	1	05/07/2004
Hirnant	10	3	05/07/2005

Location (River)	Count of 0+ classification (Fry)	Count of >0+ classification(Parr)	Date
Hirnant	1	2	10/08/2007
Hirnant	7	0	02/07/2008
Hirnant	5	2	01/07/2009
Hirnant	4	6	05/07/2010
Hirnant	6	1	28/07/2011
Hirnant	7	2	15/08/2013
Hirnant	46	5	14/09/2015
Hirnant	17	10	09/08/2016
Hirnant	83	10	18/07/2017
Hirnant	36	6	12/07/2018
Hirnant	14	5	02/07/2019
Hirnant	53	3	03/09/2021
Hirnant	3	9	28/06/2006
Hirnant	8	1	16/09/2008
Hirnant	34	18	19/08/2013
Hirnant	8	1	05/07/2004
Hirnant	10	3	05/07/2005
Hirnant	1	2	10/08/2007
Hirnant	7	0	02/07/2008

Location (River)	Count of 0+ classification (Fry)	Count of >0+ classification(Parr)	Date
Hirnant	5	2	01/07/2009
Hirnant	4	6	05/07/2010
Hirnant	6	1	28/07/2011
Hirnant	7	2	15/08/2013
Hirnant	46	5	14/09/2015
Hirnant	17	10	09/08/2016
Hirnant	83	10	18/07/2017
Hirnant	36	6	12/07/2018
Hirnant	14	5	02/07/2019
Hirnant	53	3	03/09/2021

The highest number of Salmon fry were found at NGR SH9494636260, there were 332 Salmon fry found here. This site had the highest number of parr as well. The highest number of Trout fry were also found at NGR SH9494636260, 10 Trout parr were found here. The highest number (18) of Trout parr were found at NGR SH95703230.

Other species found in the Electro-fishing surveys are:

- Stone Loach, *Barbatula barbatula*
- Minnow, *Phoxinus phoxinus*
- European Eel, *Anguilla anguilla*
- Stickleback, *Gasterosteus aculeatus*

Atlantic Salmon are a priority conservation species according to the Woodland Trust and are currently considered to be ‘under threat’. Threats to population of Atlantic Salmon include:

- River pollution
- Habitat loss
- River heating due to lack of tree cover
- Over-fishing

Similar threats affect the Brown Trout.

The European Eel is also considered critically endangered. Threats to the European Eel encounters include parasites and disease and pollution and habitat degradation.

Invertebrate

Butterflies and Moths

Table 3-6: Table 3-6 shows the invertebrate species found within the 5km buffer and after the year 2000.

Table 3-6: Butterflies and moths species point data within 5km of Aberhirnant

Common name	Scientific name
Centre-barred Sallow	*Atethmia centrago*
Cinnabar	*Tyria jacobaeae*
Dusky Thorn	*Ennomos fuscantaria*
Feathered Gothic	*Tholera decimalis*
Haworth's Minor	*Celaena haworthii*
Lackey	*Malacosoma neustria*
Sallow	*Cirrhia icteritia*
Small Heath	*Coenonympha pamphilus*
Wall	*Lasiommata megera*
Welsh Clearwing	*Synanthedon scoliaeformis*

Key species identified:

- Cinnabar, *Tyria jacobaeae*
- Welsh clearwing
- Wall butterfly

According to Norfolk Wildlife Trust, Cinnabar moth population have fallen by 83% in the last 35 years. The Cinnabar is a priority species on the UK Biodiversity Action Plan species, but only for research.

The Welsh Clearwing is not endangered but is at risk. A reason for this is because Welsh Clearwing only breeds in mature birch trees with sunlit trunks. For this reason, the Welsh clearwing has been recognized as a biodiversity priority in Wales by the Welsh Assembly

Government, under Section 74 of the Countryside and Rights of Way Act (Thomas and Graham, 2024). Wall butterflies are listed as 'high' priority (Butterfly Conservation, 2024).

Other invertebrates

Table 3-7: Other invertebrate species point data within 5km of Aberhirnant

Common name	Scientific name
Glutinous Snail	*Myxas glutinosa*
Violet Oil-beetle	*Meloe violaceus*

Key species that have been identified are:

- Violet-oil beetle
- Glutinous snail

The Violet-oil beetle is listed on the UK BAP species list. The Glutinous snail is thought to only be found in one lake in the Wales and is protected under the Wildlife and Countryside Act (1981). Threats towards the Glutinous snail include limited diet, fragility, and limited opportunities for dispersal (Freshwater Habitats Trust, 2024).

Mammal (terrestrial)

Bats

Because of the number of recordings of bats in the 5km buffer area they have been split into identified and un-identified. This refers to if the species was noted. Only the recordings of the bats which species' have been identified have been included in this report.

Table 3-8: Bats Protected Species point data within 5km of Aberhirnant

Common name	Scientific name
Noctule Bat	*Nyctalus noctula*
Pipistrelle	*Pipistrellus*
Soprano Pipistrelle	*Pipistrellus pygmaeus*
Whiskered/Brandt's Bat	*Myotis mystacinus/brandtii*

Key species identified are:

- Noctule bat
- Pipistrelle
- Soprano pipistrelle

Other mammals

Table 3-9: shows the mammals that are not bats within the 5km buffer area that were recorded after the year 2000.

Table 3-9: Other mammals species point data within 5km of Aberhirnant

Common name	Scientific name
Eurasian Badger	*Meles meles*
European Otter	*Lutra lutra*
Polecat	*Mustela putorius*
Roe Deer	*Capreolus capreolus*
West European Hedgehog	*Erinaceus europaeus*
Brown Hare	*Lepus europaeus*
European Water Vole	*Arvicola amphibius*
Stoat	*Mustela erminea*
Weasel	*Mustela nivalis*

Key species identified are:

- West European Hedgehog
- European Otter
- Eurasian badger
- Pole cat

West European Hedgehogs are classified as Vulnerable to extinction on Great Britain's Red List for mammals. Habitat degradation is one of the main threats to hedgehogs. The European Otter is near threatened and Protected in the UK under the Wildlife and Countryside Act, 1981. Main threats towards otters are habitat degradation and low river fish populations.

Badgers and Pole cats have a conservation status of ‘least concern’ but are still protected in the UK.

Reptile and Amphibian

Table 3-10: Reptile and Amphibian Protected Species point data within 5km of Aberhirnant since 2017

Common name	Scientific name
Great Crested Newt	*Triturus cristatus*
Common Frog	*Rana temporaria*
Common Lizard	*Zootoca vivipara*
Slow-worm	*Anguis fragilis*

Key species identified are:

- Great crested newt
- Slow-worm

The Great Crested Newt are under great decline and are protected in the UK. Main threats to them are land management and development. As for Slow-worms, they are also protected in the UK under the Countryside and Wildlife Act 1981. Threats to Slow-worms include predation and degradation of habitat.

Plant

This section includes the results for fungi, lichen and slime moulds.

Table 3-11: Plant Species point data within 5km of Aberhirnant since 2007

Common name	Scientific name
Glandular Eyebright	*Euphrasia officinalis subsp. anglica*
Globeflower	*Trollius europaeus*
Large-flowered Hemp-nettle	*Galeopsis speciosa*
Lesser Butterfly-orchid	*Platanthera bifolia*
Wood Bitter-vetch	*Vicia orobus*
Bluebell	*Hyacinthoides non-scripta*
Bog Pawwort	*Barbilophozia kunzeana*
Lungwort	*Lobaria pulmonaria*

The main species within the recordings are:

- Glandular Eyebright
- Lesser butterfly orchid

The Glandular Eyebright is rare in Wales and is a Priority Species under the UK Post-2010 Biodiversity Framework (North Wales Willdife, 2024). Like many orchids in the UK, the Lesser Butterfly Orchid is classed as ‘vulnerable’ in the UK.

3.11 Historic trend analysis

Historic OS mapping has been used to examine the extent of historical channel change within the vicinity of Aberhirnant Forest. The watercourse routes illustrated in the 1888 OS mapping (the earliest OS mapping available online) have been compared to current watercourses to identify areas of channel migration.

There has been minimal change to the planform of the headwater streams within Aberhirnant Forest since 1888. The narrow and steep valleys which the watercourses flow through have confined the water to the channel, encouraging incision and a lack of floodplain connectivity. As result, the majority of headwater streams have not migrated over time.

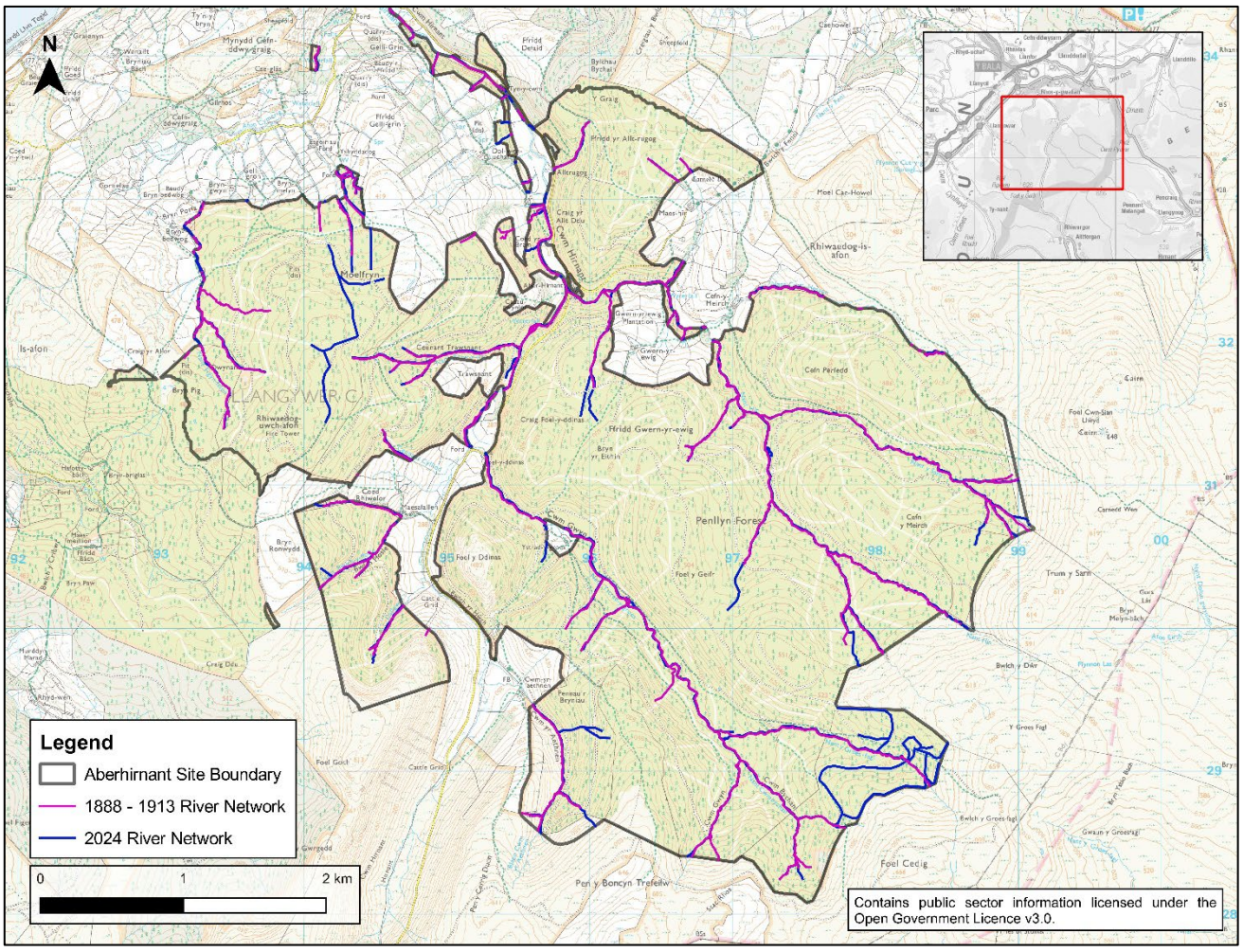

Figure 3-9: Historic mapping of watercourses within Aberhirnant Forest

Comparison between the 1888 OS mapping and present-day OS 25k mapping illustrated in Figure 3-9 shows that within the north western and south eastern areas of the forest,

headwater streams have formed where previous footpaths were located. In other areas, some of the channels identified in present day mapping are absent in the historic 1888 OS mapping. This is likely due to improvements in map resolution and surveying, resulting in better documentation of watercourses.

4. Site assessment

The site visit was conducted a week after the UK encountered a storm event (Storm Isha). There was also consistent downpour across the site at the start of the survey week, encouraging high winter flows through the headwater streams. Subsequently, examination of the bed substrate was often hampered by the increased water levels. Baseline conditions and river types across Aberhirnant Forest have been derived using observations made during this high flow event. In order to get a holistic understanding of the study area, it is recommended that a walkover is conducted during low flow conditions.

4.1 Baseline conditions

Watercourse type: Step pool channels/cascades

Example river type and sub-catchment location

Sub-catchment 1:

Sub-catchment 2:

Characteristics

The channel is steep and flows through a narrow, V-shaped valley with banks heights of approximately 4m. This topography creates high stream power following heavy rainfall events. The river has incised historically and has cut down to the bedrock layer along the channel bed. Significant vertical erosion has resulted in the formation of a stepped profile that encourages cascading, broken wave flow. This is likely to result in a well oxygenated water environment. Subsequently, channel planform is relatively straight and widths are small, ranging from 0.5m to 2m.

The headwater streams exhibit interchangeably step-pool and bedrock cascade features.

Along step-pool sections, disorganised clusters of sediment are stored in pockets of lower energy created by the larger clasts upstream of each bedrock step where there is a small gradient plateau. Smaller sediment is also observed behind angular sediment (cobbles and boulders) and bedrock outcrops that jut out into the channel from the bank toe. Although these step-pool channels are relatively stable, variation in channel width can be observed at locations where woody material has fallen into the channel and pushed flow laterally towards the banks.

Along bedrock cascade sections, there is an absence of loose sediment as the high flow velocities, generated by the smoother, bedrock lined channel and steep channel gradient, has resulted in a high transport capacity. The channel is well connected to the base of the valley slope, which forms a limited riparian zone, due to the incised nature of the channel.

The valley sides are dominated by conifer trees that shade the forest floor which prevents the growth of smaller, less emergent shrubs/plants, limiting the riparian zone further.

The cobbles and boulders in channel provide habitat for aquatic species, including for spawning for species such as Atlantic Salmon. However, the steps may provide a barrier for some fish species, as their height increases.

These watercourse types are typical of steep, upland watercourses.

Watercourse type: Plane bed

Example river type and sub-catchment location

Sub-catchment 5:

Characteristics

The channel flows through a V-shaped valley with bank heights of approximately 2-3m. The channel is moderately steep with a slope angle of 4 degrees over 6m, which encourages high flow energy during heavy rainfall events that has caused incision and disconnection from the local floodplain. The channel is largely featureless, straight and has a fairly continuous width of 1m for the majority of its length, which encourages a run flow biotype. However, in areas where large woody material has fallen into the channel, there are localised increases in width resulting in minor depositions (due to a reduction in flow velocity) and some connectivity with the floodplain where erosion inputs small amounts of sediment into the channel.

The channel bed is comprised of an assortment of angular and more rounded cobbles, suggesting that sediment is transported from upstream and eroded on route as sediment is transported downstream (hence a more rounded appearance), as well as inputted from the banks, supplying more angular cobble material to the channel bed. Finer gravels and silts are winnowed out by the high-energy run flow.

The floodplain along the Afon Hirant contains broadleaved woodland with scrub understorey with Bramble, Rhododendron ponticum and Silver Birch present, as a result of there being fewer trees shading the ground.

These channels provide important aquatic and terrestrial habitat for a range of species. The channel and channel bed provides spawning habitat and material for Atlantic Salmon, Brown/ sea trout and invertebrates.

Whilst the riparian zone provides habitat and connectivity in the landscape for mammals including bat species and Otter.

This watercourse type is often located immediately upstream of the confluence with the main river where slope gradients are slightly slacker.

Watercourse type: Multi-thread

Example river type and sub-catchment location

Sub-catchment 4:

Sub-catchment 5:

Characteristics

Differences in topography and hydrological regime between sub-catchments have resulted in some multi-threaded systems flowing through a V-shaped valley with a wider valley floor of approximately 20-30m along the Afon Hirnant. As a result of a less confined valley shape and a wider floor, the main channel has been able to laterally migrate and create a series of multi-thread channels at high flows that split and converge around emergent trees and islands. There are significant deposits of fine sediment (comprised of silt, sand and gravels)

in areas that are isolated from low flow, as well as on the inside of channel bends where flow velocities are reduced. Sediment inputs to the system are likely to originate from the earth banks and islands that get eroded when the system avulses or have been transported downstream from land where soils have been displaced by agricultural practices.

There is connectivity with the immediate floodplain and riparian zone that consists of broadleaved species and scrub vegetation, including Oak Quercus sp,, Willow Salix sp., Silver Birch Betula pendula and Downy Birch Betula pubescens. The multi-thread channel creates a more varied habitat profile, with terrestrial habitats present as islands between the aquatic threads. This can provide habitat and refuge for species such as Otter, fish including Atlantic Salmon, European Eel and support invertebrates.

Forest drains: U-shaped drainage channels

Example forest drain and sub-catchment location

Sub-catchment 2:

Characteristics

This linear drainage channel has been artificially dug from the top to the bottom of the hill slope, between conifers, in order to transport precipitation and overland flow away from conifer plantation areas. These drainage channels discharge directly into a watercourse or a road drain that runs perpendicular to the slope.

The channel is more U-shaped with gently, sloping banks. Channel width varies between 0.5m and 1m. It is likely that the channel was originally uniform and square, but overtime weathering and mobilisation of soil material during heavy rainfall events has since changed the channel geometry. Human interactions, through forestry practices such as tree removal, planting and drainage channel creation, are also likely to have made ground material more unconsolidated and easily mobilised during rainfall events contributing to a shallower and wider profile.

The conifers sit on mounds of soil, held together by a dense network of roots. These mounds form the top of the drainage channel banks.

The ground is bare, due to shading from the coniferous trees preventing the growth of less emergent vegetation, with only a littering of woody material from surrounding conifers.

Forest drains: Square drainage channels

Example forest drain and sub-catchment location

Sub-catchment 2:

Characteristics

This linear drainage channel has been artificially dug from the top to the bottom of the hill slope, between conifers, in order to transport precipitation and overland flow away from conifer plantation areas. The majority of these drainage channels discharge directly into a watercourse or road drain that runs perpendicular to the slope, whilst others (such as shown in Sub-Catchment 2) are disconnected and do not discharge directly into the downstream watercourse. As a result of the machinery used, the channel is very uniform, incised and trapezoidal with a width of approximately 0.5-0.8m. Subsequently, there is no flow variation within the drain resulting in a lack of in-channel features. The drainage channel is ephemeral; it is usually dry until a heavy rainfall event occurs, and a run flow biotype is encouraged.

The surrounding ground is very soft, boggy and covered in scrub moss species and Sphagnum species(Sphagnum sp.), indicating a high-water table and good groundwater connectivity.

Forest drains: Natural depressions

Example forest drain and sub-catchment location

Sub-catchment 2:

Characteristics

Artificial drainage channels were not identified in all visited forestry coupes. Natural depressions were prevalent throughout most areas, creating natural micro-pathways and temporary storage areas for overland flow. These natural depressions help to attenuate any flow by preventing the channelisation of water downslope towards road drains and watercourses. As a result, there is more infiltration into groundwater stores. These areas were dominated by Sphagnum, due to the higher level of water being retained compared to the surrounding higher ground.

Forest drains: Disused forest tracks

Example forest drain and sub-catchment location

Sub-catchment 4:

Characteristics

Harvesting tracks were prevalent through some forestry coupe areas, created as a result of large machinery and transport frequently using these routes. Subsequently, the tracks are very uniform in their width and depth. Large amounts of tree fall across the tracks and vegetation growth within the surface depressions indicate their disuse. During heavy rainfall events, some surface runoff is likely to be channelised down these tracks, transporting flow and fine sediment quickly away from the coupe areas and towards forest road drains and watercourses.

Forest road and road drains: Vegetated road material

Example forest road and sub-catchment location

Sub-catchment 1:

Characteristics

The forest road is constructed on angular aggregate and are often coated in muds/clay/gravels from vehicle movements - which mainly sits on the surface. Roads are occasionally 'blinded' with a layer of fines (which may include some organics such as moss, grasses and pine needles) to provide a smoother running surface for vehicles and help seal the road, making the material more stable and less susceptible to being displaced by vehicles or heavy rainfall events.
The pine needles along these roads have been moved into a series of steps, likely as a result of large amounts of surface water mobilising this material and depositing it as velocities reduce.

Forest road and road drains: Loose road material

Example forest road and sub-catchment location

Sub-catchment 1:

Characteristics

The forest road is constructed of aggregate, however there may be some residual soil/clay in the mix from the excavation and processing phase.
Due to the nature of the forest road unbound construction design, water ingress combined with certain loading can result in loose stone being ejected from the road surface, resulting in potholes forming. These potholes fill with water, which exacerbates the stability issue, and causes further increase in pothole sizes. NRW have a road defect system whereby potholes are supposed to be reported to the Integrated Engineering teams, for them to carry out road repairs. Potholes are often not reported (as hauliers are concerned it may mean a temporary road closure - which may affect their ability to collect timber) and consequently, large potholes or road failures occur.
It is likely that during heavy rainfall events, loose road material will be mobilised and moved downslope, eventually reaching a stream that will transport and discharge it into the Afon Hirnant, or reach a relief culvert that will discharge it onto the bank below the road. As a result, this will deteriorate water quality conditions in the watercourse due to increased sediment levels, which can impact the species inhabiting the watercourse.

Forest road and road drains: Very loose road material

Example forest road and sub-catchment location

Sub-catchment 5:

Characteristics

The forest road is comprised of clay and gravels. As a result of significant pressure from heavy loaded vehicles using the road, the road aggregate (in areas) breaks down into loose surface stone and forms fine particles within the road formation. In the summer, this can present as dust, and in the wetter periods, this dust mixes with the rain and can cause discoloured surface water ‘wash off’.
It is evident that surface water collects on the road during heavy rainfall events as material has been excavated on some road edges to create small pathways in order to prevent the ponding or the running of surface water. This excavation was identified at locations where road maintenance (in the form of re-establishing the road camber) had not been carried out and ruts have formed, resulting in water failing to shed the road surface and instead travel longitudinally along the road, causing erosion and scour further downslope.

Forest road and road drains: Road drains

Example forest road and sub-catchment location

Sub-catchment 5:

Sub-catchment 1:

Characteristics

A drain runs alongside the forest road, directing overland flow from the surrounding hills towards a relief culvert that flows underneath the road. Water from the culvert then spills out onto lower ground. Drains within the study area have been artificially constructed (uniform, square geometry) to match the road geometry.

The road drains are often overlain with smaller gravels and silt that has been transported down from higher areas within the forest, as well as off the adjacent roads. They also tend to be well vegetated, with Soft Rush Juncus effusus abundant, and Opposite-leaved Golden-saxifrage Chrysosplenium oppositifolium also noted in areas. They are also narrow with a width approximately ranging between 0.25m to 0.5m and following a maximum road gradient of 10%, encouraging fast flow during rainfall events. As a result, the road drains

are largely ephemeral. The majority of road drains were inundated during the walkover as there had been heavy rainfall the week prior, as well as during the site visit.

In order to reduce the amount of surface water discharging into watercourses from the road network and adjacent slopes, catch pits have been dug alongside roads to widen the road drain and encourage a reduction in flow velocity and the deposition of finer sediments. This prevents the transportation of finer sediment downstream and into the main Afon Hirnant. A small number of catch pits were observed directly upstream of culverts.

Within sub-catchment 1 at a location (NGR SH 97244 31006) where the road is constructed in a low area of topography, relief culverts have been installed with catch pits prior to discharge on the bank below (where the watercourse is in the immediate vicinity) in order to prevent water from being directed to a single point of discharge at the nearby bridge location. This is per UKFS guidance.

Open ground: Areas with no conifer plantation

Example open ground and sub-catchment location

Sub-catchment 1:

Characteristics

Areas of open ground are found infrequently across the study area. Larger clusters are predominantly located at the top of the study area. The open ground is often covered by a dense layer of shrub vegetation including heather, tussocks of Purple Moor-grass Molinia caerulea, Bracken Pteridium aquilinum and moss, that help to bind the peaty soils. Regrowth of conifers is also common. Rainfall is intercepted by the vegetation. Natural linear depressions in the topography provide pathways for overland flow to move downslope.

4.2 Channel slope gradient

19 clinometer measurements were recorded during the site visit to Aberhirnant Forest. These measurements reflect gradients within a number of natural watercourses and drainage channels and were used to help inform river types and observed processes. The majority of the readings were taken looking upstream. Gradient measurements have been recorded in degrees. Channel slope gradients can help aid discussions around the implementation of features to attenuate flow and sediment transport. For example, channel slope is an important factor to consider when assessing the suitability of leaky barriers.

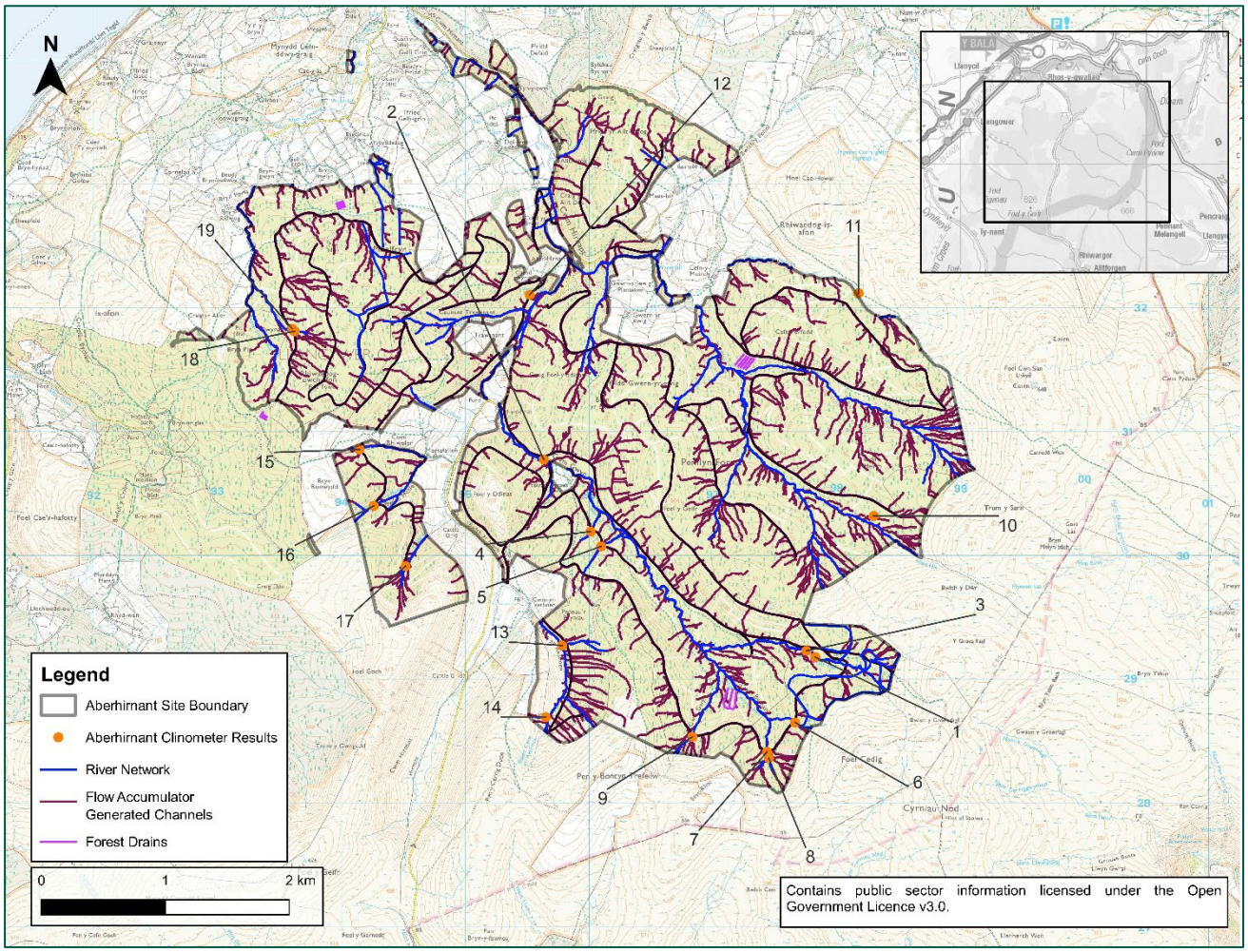

Figure 4-1: Clinometer measurements recorded in watercourses and drainage channels across Aberhirnant Forest

Table 4-1: Channel slope gradient recorded within Aberhirnant Forest

ID	Channel slope gradient recordings in degrees	Channel slope gradients in percentages (1.d.p)
1	1.6 degrees over 15m	2.8%
2	4.2 degrees over 6m looking downstream	7.3%
3	7.2 degrees over 15m	12.6%
4	12 degrees over 20m upstream culvert inlet	21.3%
5	10 degrees over 10m upstream of culvert inlet	17.6%
6	16.8 degrees upstream culvert inlet	30.2%
7	7.2 degrees over 15m upstream of culvert inlet	12.6%
8	12.8 degrees over 7m	22.7%
9	9 degrees over 10m upstream culvert inlet	15.8%
10	4 degrees over 6m	6.9%
11	4 degrees over 8m looking downstream	6.9%
12	28 degrees over 10m upstream of culvert inlet	53.2%
13	18 degrees over 15m	32.5%
14	18 degrees over 10m	32.5%
15	13.2 degrees over 20m upstream of culvert inlet	23.5%
16	15.8 degrees over 20m upstream of culvert	28.3%
17	13.6 degrees over 15m	24.2%
18	16.8 degrees over 6m upstream of culvert inlet	30.2%
19	10.2 degrees over 8m	17.9%

5. Pressure identification

Together, the desk-based assessment and site walkovers have enabled the development of a holistic understanding of the existing conditions within the Aberhirnant Forest study area, and the identification of key system pressures which have impacted sediment dynamics and habitats. As a result, this has helped guide the formation of integrated catchment management opportunities to target/mitigate the existing key pressures (Section 7).

Pressures have been mapped across the Aberhirnant Forest. This data is provided separately as a series of feature classes within a geodatabase for display within a Geographic Information System (GIS). It is important to note that these pressures only reflect the current conditions within Aberhirnant Forest.

5.1 Summary of key pressures

The following identified pressures are a combination of study-area wide and localised pressures.

Key pressure: Timing of clearfell and thinning forest operations

- Within the study area, certain forest coupes have been felled and large quantities of windrow left behind. This was particularly evident along a recently felled 400m wide (approximately) slope within Sub-Catchment 2.
- More forest coupes have been approved for felling in the next few years.
- Not mapped as it is a forest-wide pressure and is predominantly the cause of other pressures identified below.

Impacts on study area

- Machinery used to fell and process the trees can add pressure to the soils and make them more compact and less porous.
- Tree removal could result in ground disturbances, leading to increased silt inputs into drainage channels, headwater streams and subsequently, the main Afon Hirnant.
- Tree removal will also reduce the amount of woody material that naturally falls into watercourses, hence why limited large woody material was observed in headwater streams throughout Aberhirnant Forest. This has the potential to impact species in the watercourses due to the impacts through alterations in the pH and increased levels of sediment leading to potential impacts including, increased turbidity, alteration in oxygen levels and reduction in suitable spawning habitat,
- Phosphate and nitrogen compounds can be released into streams via surface/subsurface flow through tree removal, depleting water quality and impacting freshwater species. Water quality will also be depleted in the main Afon Hirnant river as a result of the poor-quality water discharging into it.
- Felling can also cause increased acidic flushes, impacting on the mobilisation of heavy metals and affecting aquatic species through changes in the water pH.

Example of pressure identified through field survey

Sub-catchment 2:

Opportunities to mitigate (see Section 7.1)

- Embed Sustainable Forest Management practices
- Increase riparian woodland
- Add large woody material / leaky barriers
- Add bales or geomembrane

Key pressure: Forest drains

In areas of dense conifer plantation, artificial drainage channels have been excavated downslope to encourage water to drain quickly.

Impacts on study area

- If peat is being drained, then there will be an impact on the carbon sink and lowering of the water table and has the potential to lead to peat erosion. This could alter the habitats present with a move towards species tolerant of drier conditions.
- A greater drainage density helps to increase run off towards the main Afon Hirnant. Can lead to increased in-channel water levels and increased risk of flooding downstream. Can also lead to increased levels of potential washout of habitat, aquatic biota and fish spawn (within the headwater streams, channels and main Afon Hirnant).
- Water that reaches the Afon Hirnant will not be filtered through an active and well-connected riparian buffer zone, therefore will be quite acidic. Could lead to depleted water quality of the main Afon Hirnant and an impact on freshwater species through alterations in the pH and increased levels of sediment leading to potential impacts

including, increased turbidity, alteration in oxygen levels and reduction in suitable spawning habitat.
- The species likely to be impacted are fish species including Atlantic Salmon, Trout, and invertebrates.

Example of pressure identified through field survey

Sub-catchment 2:

Opportunities to mitigate (see Section 7.1)

- Add large woody material / leaky barriers
- Bank lowering
- Install root wads
- Add heather bundles

Key pressure: Loose road material

Unconsolidated road material will be displaced during heavy rainfall events and by vehicles that use the road. The fine sediment will enter the headwater streams and drainage channels and be washed downstream into the main Afon Hirnant or be conveyed to a relief culvert and discharged below the road into vegetated areas.

Impacts on study area

- Fine sediment inputs into headwater streams, drainage channels can result in decreases in water quality and increased water turbidity. This can affect dissolved oxygen levels, therefore impacting freshwater species. As this water is discharged

into the Afon Hirnant, decreases in water quality, turbidity and dissolved oxygen levels within these main rivers will also occur.
- Loose road material inputs will also affect the quality of gravels and subsequent habitat within the watercourse, which will affect the biota.
- Loose road material inputs were seen particularly in Sub-Catchment 5.

Example of pressure identified through field survey

Sub-catchment 5:

Opportunities to mitigate (see Section 7.1)

- Clear catch pits
- Add catch pit
- Add bales or geomembrane

Key pressure: Road drain

Surface run off draining the forest slopes will drop into the road drain and be directed towards a culvert to allow the passage of water underneath the road.

Impacts on study area

- Sediment and material transported during heavy rainfall events can block the under-road culverts, resulting in a large pooling of water behind the structure. However, if this occurs, flow will often continue along the road to the next relief culvert or flow will overtop the road and sediment will be washed onto the bank below.
- The road drain will direct water from a large expanse of slope, towards one convergence point (a culvert) often located along every 100m of road within Aberhirnant Forest (adhering to UKFS guidance), where it will continue flowing quickly down a drainage channel/stream towards the main Afon Hirnant or onto a vegetated area. Therefore, overland flow is not able to disperse along the lower floodplain area and be attenuated or filtered before reaching the main river. As a result, flood risk could be increased downstream and water quality will decrease.

Example of pressure identified through field survey

Sub-catchment 5:

Opportunities to mitigate (see Section 7.1)

- Clear catch pits
- Add leaky barriers and woody material
- Add catch pit
- Add bales or geomembrane
- Install root wads

Key pressure: Culvert

There have been physical modifications to the headwater streams and drainage channels involving replacement of open channel with culverted sections to direct flow downstream, underneath the forest roads.

Impacts on study area

- Direct loss of habitat.
- Lack of longitudinal and lateral connectivity.
- Barrier to fish migration if fish are using the watercourse and suitable modifications have not been included in the culvert design

- Scour of the bed downstream of the culvert and bed incision in the reach downstream (as observed in many places) resulting from a reduced sediment supply.
- Potential impacts on fish and invertebrate populations.

Example of pressure identified through field survey

Sub-catchment 2:

Opportunities to mitigate (see Section 7.1)

- Culvert replacement

Key pressure: Lack of / degraded riparian vegetation

In sections along the headwater streams within Aberhirnant Forest, the riparian corridor is limited with only narrow strips of woodland and vegetation confined to the banks of the stream, or altogether absent due to conifer planting. The terrestrial riparian habitat potential is limited within the conifer plantation areas as conifer trees outcompete native tree species and also prevent the growth of less emergent and aquatic in channel vegetation due to significant shading.

Impacts on study area

- Potential pollution; degrading water quality.
- Acidification within the main river channel (i.e. Afon Hirnant) leading to changes in water pH with impacts upon flora and fauna using the watercourses.
- Reduced quality of ecological corridors through the forestry to allow species to travel.
- Lack of habitat stability due to felling occurring at set periods.
- Fine sediment release.
- Bank erosion and bank instability.
- Limited habitat potential.
- Lack of woody material resupply due to a lack of riparian vegetation.

Example of pressure identified through field survey

Sub-catchment 2:

Sub-catchment 4:

Opportunities to mitigate (see Section 7.1)

- Inrease riparian vegetation
- Create buffer between watercourse and areas of conifer plantation

Key pressure: Deposited roadside material

Within the Forestry Block, it is common practice to import type 1 aggregate in bulk preparation for road maintenance operations. This aggregate is deposited on the side of roads. These will be located throughout the block to minimise haulage distance during actual road maintenance operations, thereby reducing C02 emissions from having vehicles travelling back and forth.

Impacts on study area

- During heavy rainfall events some of this deposited sediment could be remobilised and re-enter and watercourse and the main Afon Hirnant resulting in decreases in water quality and increased water turbidity. This can affect dissolved oxygen levels, therefore impacting freshwater species. This has the potential to impact designated species in the watercourses downstream such as European Eel and Atlantic Salmon.

Example of pressure identified through field survey

Sub-catchment 1:

Opportunities to mitigate (see Section 7.1)

- Add leaky barriers and woody material
- Clear catch pits
- Improve placement of roadside material
- Add catch pit
- Install root wads
- Micro bund

Key pressure: Excavated material

Excavated material/sediment removed from catchpits (typically located on upstream side of forest track culvert) often just left on bankside of catchpit rather than being properly extracted from the area and disposed of in a more appropriate location away from the watercourse.

Impacts on study area

- During heavy rainfall events some of this excavated sediment could be remobilised and re-enter and watercourse and the main Afon Hirnant, resulting in decreases in water quality and increased water turbidity. This can affect dissolved oxygen levels, therefore impacting freshwater species.

Example of pressure identified through field survey

Sub-catchment 5:

Opportunities to mitigate (see Section 7.1)

- Remove excavated material
- Add leaky barriers and woody material
- Install root wads
- Add bales or geomembrane
- Micro bund

Key pressure: Invasive Non-Native Species (INNS)

The surveyed areas were largely observed to be absent of INNS, however, stands of *Rhododendron ponticum* were noted throughout the woodland, especially along the river Hirnant, with some of the stands forming relatively large dense areas of the undergrowth.

Impacts on study area

- The presence of INNS could result in their spreading within the woodland and surrounding area. This would alter the habitats and composition of species present within the woodland.
- Rhododendron can form dense areas of shrub which shades out and out competes native species. It is also highly spreadable and if not controlled will spread to dominate the understorey habitats of the woodland.

Example of pressure identified through field survey

Sub-catchment 5:

Opportunities to mitigate (see Section 7.1)

- Invasive Non-Native Species (INNS) control

Key pressure: Agricultural management pressures

At the upper extent of the area surveyed, intensive grazing borders the River Hirnant, with little to no established riparian zone

Impacts on study area

- Potential pollution; degrading water quality.
- Potential nutrient delivery to the main river channel (i.e. Afon Hirnant) leading to impacts upon flora and fauna using watercourses.
- Fine sediment release.
- Bank erosion and bank instability.
- Limited habitat potential.
- Lack of riparian tree cover and rougher vegetation. There will be a lack of shading which will lead to overheating of watercourses.
- Poaching of banks by livestock, leading to over-widening and shallowing of the river.

Example of pressure identified through field survey

Sub-catchment 3:

Opportunities to mitigate (see Section 7.1)

- Increase riparian vegetation
- Add leaky barriers and woody material

Key pressure: Bank modification

Gabion baskets were observed along the Nant Ystrad-y-groes, on the right bank downstream of a bridge at NGR SH 95677 30744.

Impacts on study area

- Limited lateral erosion and or migration of the watercourse.
- Loss of bankside habitat.
- Loss of hydromorphological diversity.
- Acceleration of in-channel velocities can lead to unintended geomorphic response such as bed incision or bank instability downstream. However, this was not observed downstream on site, likely due to the gabion baskets only extending over an approximate bank section of 5m and only being located on the right bank. As a result, there is little influence on flow velocities.

Example of pressure identified through field survey

Sub-catchment 2:

Opportunities to mitigate (see Section 7.1)

- Replacing with soft engineering options

Key pressure: Bridge

There have been physical modifications to the banks of headwater streams and drainage channels involving the installation of a bridge structure that spans the channel to allow the passage of forestry vehicles over watercourses.

Impacts on study area

- Direct loss of bankside habitat.
- Lack of lateral connectivity at bridge location. Longitudinal connectivity does not seem to be affected at site locations as the bridges only span the river and there are no in-channel structures such as a bridge apron. Bed substrate appears to be consistent from upstream to downstream of structure, i.e. cobbles and boulders.
- Scour around bridge abutments.
- Acceleration of in-channel velocities.

Example of pressure identified through field survey

Sub-catchment 5:

Opportunities to mitigate (see Section 7.1)

- Replacing with soft engineering options

Focus area scale pressure maps have been created to show examples of site-specific pressures (see Figure 5 1, Figure 5 2 and Figure 5 3).

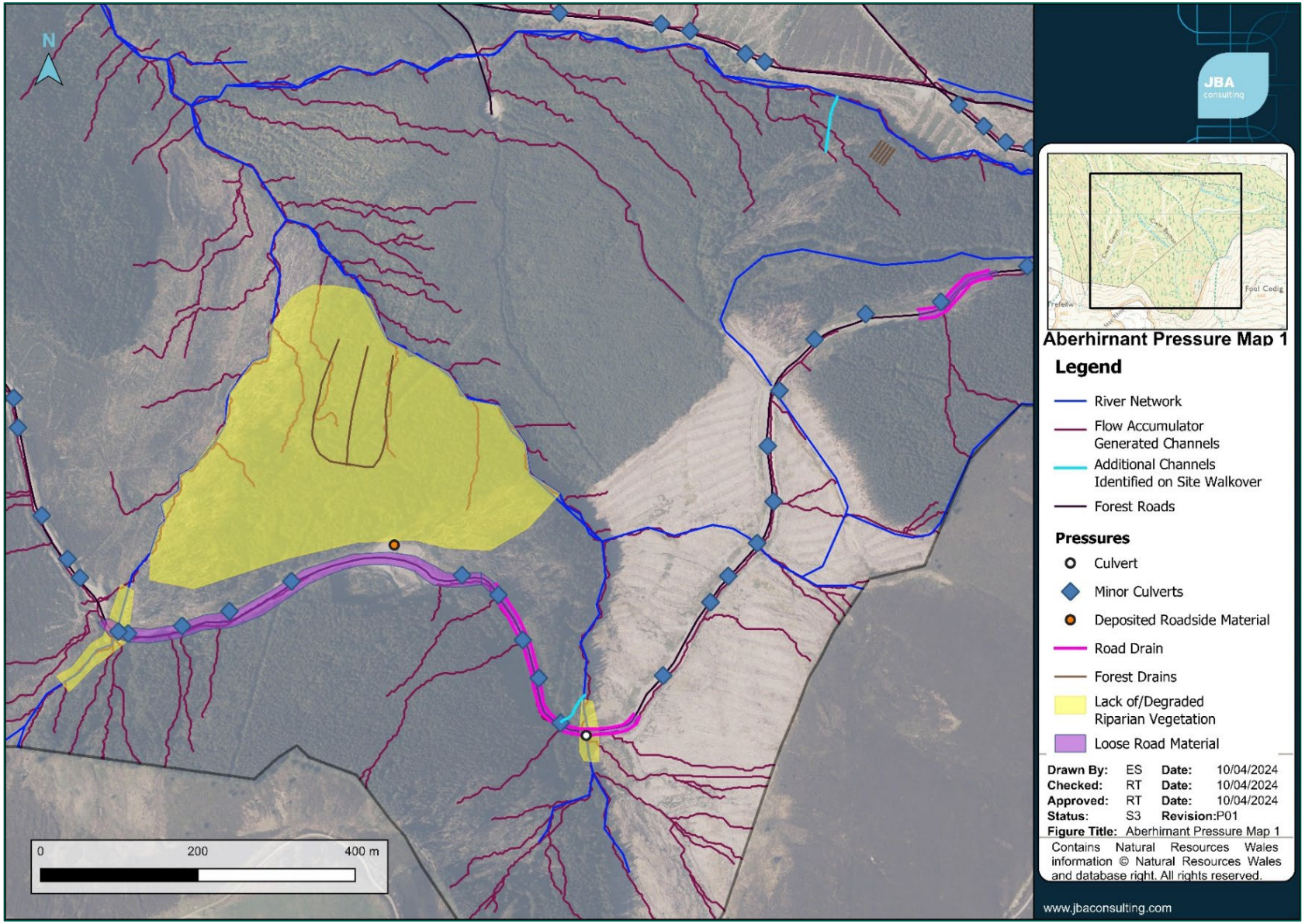

Figure 5-1: Pressures identified at NGR SH 97141 28750 (Sub-Catchment 2, Area 18 in Summary of Baseline Conditions Map)

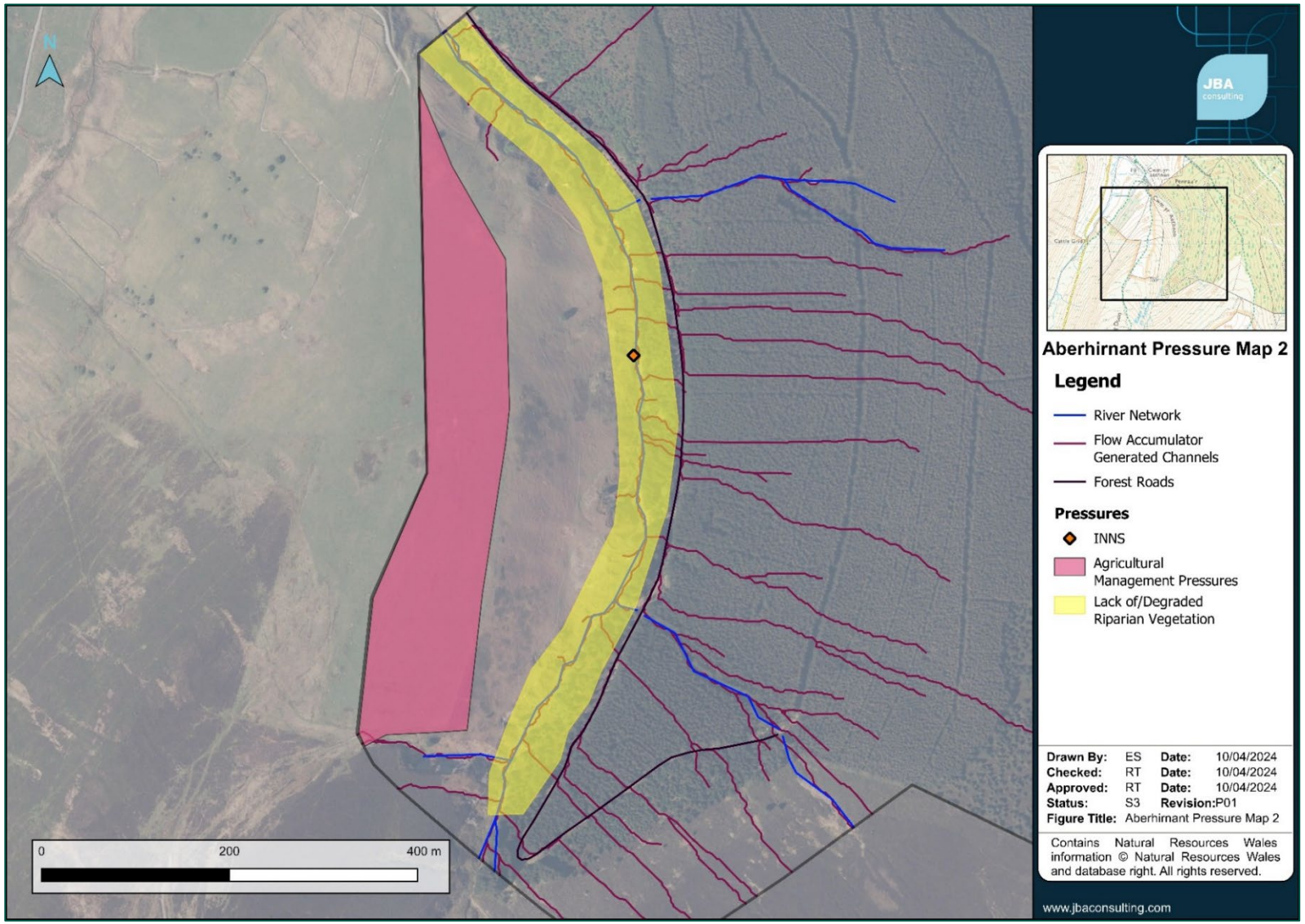

Figure 5-2: Pressures identified at NGR SH 95816 29082 (Sub-Catchment 3, Area 17 in Summary of Baseline Conditions Map)

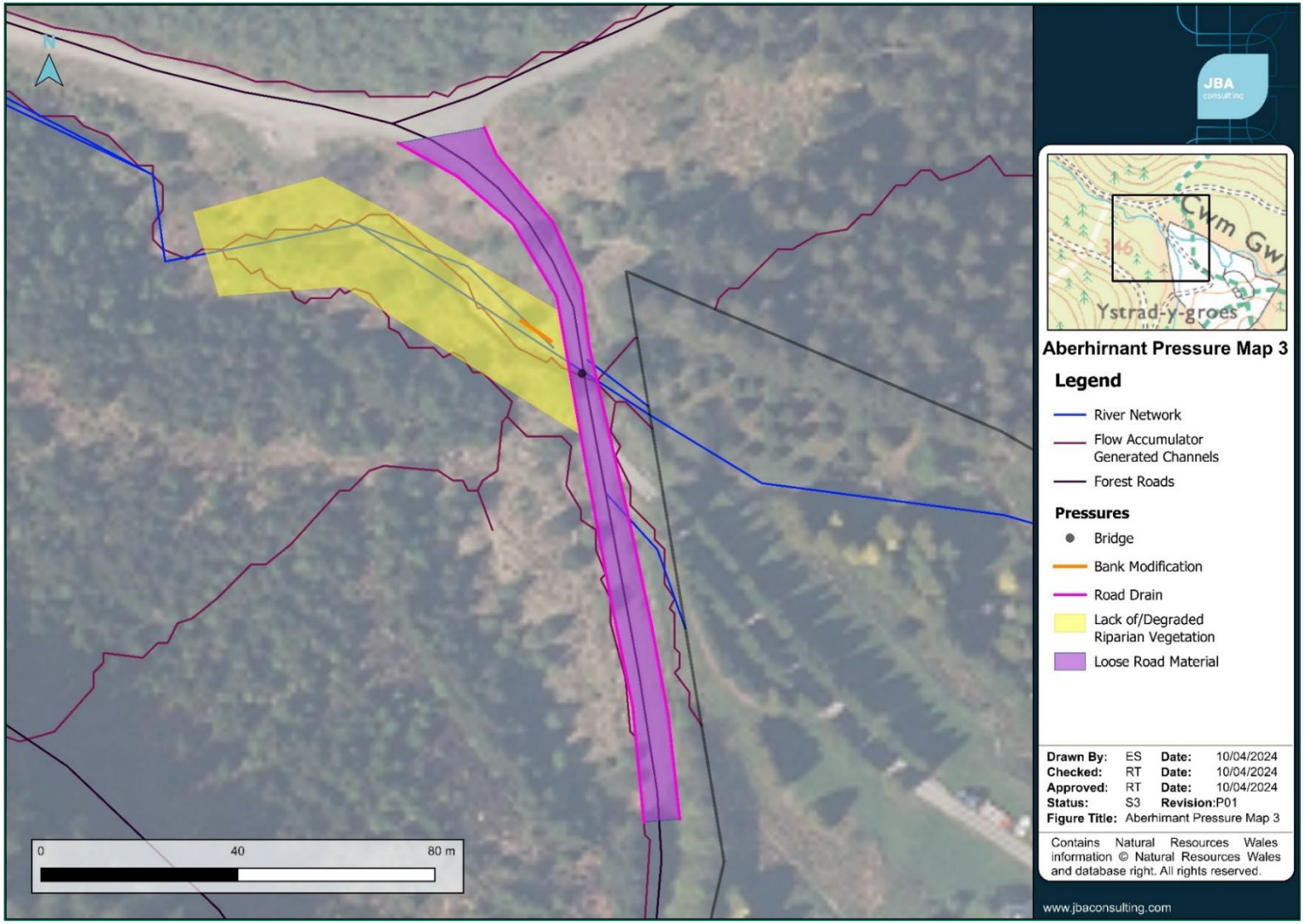

Figure 5-3: Pressures identified at NGR SH 95676 30744 (Sub-Catchment 2, Area 15 in Summary of Baseline Conditions Map)

6. Summary of baseline conditions

Information collected during the desk-and site-based assessments has been integrated and analysed to develop a summary of baseline conditions, which is presented in Figure 6-6 and Figure 6-7. This summarises the key processes, form and ecological function across the study area, as well as sediment sources and sinks generated from both natural processes and from artificial influences (i.e. physical modification, land use) which constitute system pressures.

6.1 Existing conditions

The drainage of water within the Aberhirnant Forest, from the hillslopes to the confluence with the main Afon Hirnant, has been largely impacted by both natural steep topography and forestry practices. Superficial pathways in the form of linear drainage channels and road drains have been artificially created to encourage faster conveyance of flow and sediment downslope towards the main watercourse and away from conifer plantations during heavy rainfall events. The presence of disused harvesting tracks also exacerbates the conveyance of flow and sediment from forestry coupe areas. The steep topography greatly controls the typical watercourse types observed in the Aberhirnant Forest. The majority of the headwater streams are typical of step-pool river systems and bedrock cascade river types, characterised by steep channels that flow through narrow, V-shaped valleys and have stepped profiles due to significant vertical erosion exposing bedrock. Other watercourses within the study area are typical of plane bed systems as slope gradients reduce and channels transition towards more dynamic watercourse types. These channels continue to be confined by moderately steep V-shaped valleys; however, valley floors are marginally wider, allowing better connection to the riparian zones. The morphology tends to be featureless (with a lack of in-channel bed forms and no organised channel bed structure) and straight. This channel type has more potential to change than the more stable bedrock and step-pool cascade watercourse types. Multi-thread channels are present along the Afon Hirnant as a result of a less confined valley shape, wider valley floor and active sediment supply. The main channel has been able to laterally migrate and avulse during high flows, creating a series of multi-thread channels that bifurcate and converge around emergent trees and islands. This creates extensive and varied habitat which is of high value due to its distinctiveness in the landscape and suitability to support species.

The site is characterised by significant areas of coniferous plantation woodland, with areas of largely self-set broadleaved trees along the more open riparian areas, though self-set conifer regeneration was noted throughout the site in open areas, riparian areas and along the forest tracks. The Afon Hirnant divides the site, providing an important corridor in the landscape. The dense coniferous plantation on the steeper slopes allows for very little ground layer or understorey vegetation to develop and instead these areas were dominated by a dense blanket of bryophytes. Above the site, the habitat opens into moorland.

The Afon Hirnant is a valuable habitat supporting a number of priority species, including fish species, Otter and Bats. Records from the electrofishing surveys are limited to outside of the site boundary, with one point just outside of the site boundary on the River Hirnant. This point indicates that fish including Atlantic Salmon, Trout, European Eel, Stone Loach, Minnow and Stickleback have been recorded.

The forestry block contains tributaries that flow into the river, providing habitat opportunities for species utilising the main channel, the lower gentler sloped watercourses in the forestry block are likely to support the designated species present with the Afon Hirnant. Higher up the forestry block the watercourses become steeper channels. Due to the surrounding forestry, the higher watercourse reaches are likely be fairly acidic in nature which is generally more favourable for Brown Trout if they are able to access them. The use of culverts to allow the creation of forestry tracks is likely to limit the connectivity of the watercourses for fish species.

Litter has been observed along some of the headwater streams as well as scattered within some conifer plantations in the study area. Litter can lead to a degraded water quality and impacts on fish and invertebrate populations. It also has a negative impact on the visual appearance of a landscape. This should be removed from Aberhirnant Forest.

6.2 Sediment sources and sinks

Although small, localised areas of erosion were evident along the banks of the headwater streams and drainage channels, particularly in areas where woody material had fallen across the channel or around bedrock outcrops, the main sediment sources identified within the walkover extent include felling, hillslope failure, mounded road material (stone stockpiles) and excavated material.

Conifer felling can provide large amounts of fine-grained silt and sediment (less than 2mm) to drainage channels through significant ground disturbance when trees are cut down and trunks removed from site, depending on the standard of practice employed. The disturbed fines are transported towards the main river during heavy rainfall events and as a result, degrades the water quality. This forestry operation has occurred in many locations across the study area and is planned to occur within coupes in the future, therefore fine sediment release through felling will continue to be an issue to manage appropriately. Felling as a catchment pressure and sediment source has not been mapped on the figures below as it occurs forestry wide.

Localised hillslope failure has occurred as a result of weathering along hillslopes, which has caused material (e.g. mix of earth and sand) to become unconsolidated and easily erodible. Weathering has also resulted in the deformation of slate-composed slopes in some areas of the forest. Material from the unstable slopes is likely to be mobilised during heavy rainfall events and transported via road drains and forest drains into headwater streams and the main Afon Hirnant.

Mounds of lime chips have been deposited in the outlet of culverts so that flowing water can mix with the lime and react to alter the pH of the water in order to mitigate acidification of headwater streams and the main river (Afon Hirnant) within the vicinity of Aberhirnant Forest.

Throughout the Forestry Block, it is common practice to import type 1 aggregate in bulk preparation for road maintenance operations. Therefore, frequent deposits of this aggregate were observed on the side of roads during the walkover, particularly in areas where drainage systems are in place e.g. passing places at roadside or turning areas. Some material within the deposit is likely to become mobilised during heavy rainfall events and enter drainage channels and nearby streams and the main Afon Hirnant, resulting in decreases in water quality and increased water turbidity.

Figure 6-1: Mound of deposited roadside material. NGR: SH 96126 31719

Small depositions of sediment, such as gravels and small cobbles (likely sourced from the riverbanks), are evident behind woody material in headwater streams, due to reductions in flow velocities. However, as these sediment stores are very localised and small, they are not considered to be a main sink identified within the walkover extent so have not been mapped. Identified main sediment sinks include catch pits, large depositions behind root wads and depositions within the multi-thread channel system.

A significant number of catch pits were observed along road drains throughout the study area. At some locations, a series of catch pits were identified along the road drains within the vicinity of a culvert. These catch pits have been dug to reduce flow velocities on approach to the culvert to encourage deposition of sediment and prevent it from being entrained downstream and discharged into the main Afon Hirnant. Several of the catch pits on site were full of fine sediment. Where catch pits had been cleared out, excavated material (mainly composed of small gravels and silt) could be found located within the vicinity of the catch pit. Geomembrane was also observed across a road drain to help encourage greater deposition of fine sediment, although it had partially collapsed.

Geotextiles are often used to slow the flow during construction projects, acting as check dams, and to mitigate sediment rated pollution incidents. Normally, these are removed after operations, but the one at NGR: SH 97443 28416 has been left behind.

Figure 6-2 (left): Geomembrane across vegetated road drain. NGR: SH 97443 28416 and Figure 6-3 (right): Catch pit. NGR: SH 96020 31663

There were also large fine sediment depositions around some root wads of fallen trees that are located in overland flow pathways and within the multi-thread channel system around emergent trees and on the inside of channel bends where flow velocities are reduced, creating silt and gravel bar features.

To summarise, there is evidence of natural sediment inputs into the study watercourses via hillslope erosion and localised bank erosion. Erosion is a natural process by which sediment is supplied to the river system. However, there is evidence that forestry management practices, such as felling and planting within the coupes, have exacerbated rates of erosion, leading to increased amounts of fine-grained sediment displacement. This sediment could be observed in catch pits throughout the study area, as well as behind root wads of fallen trees located on forest slopes.

Figure 6-4 (left): Silt deposition around a root wad. NGR: SH 98350 30358 and Figure 6-5 (right): Silt depositions within the multi-thread channel system.

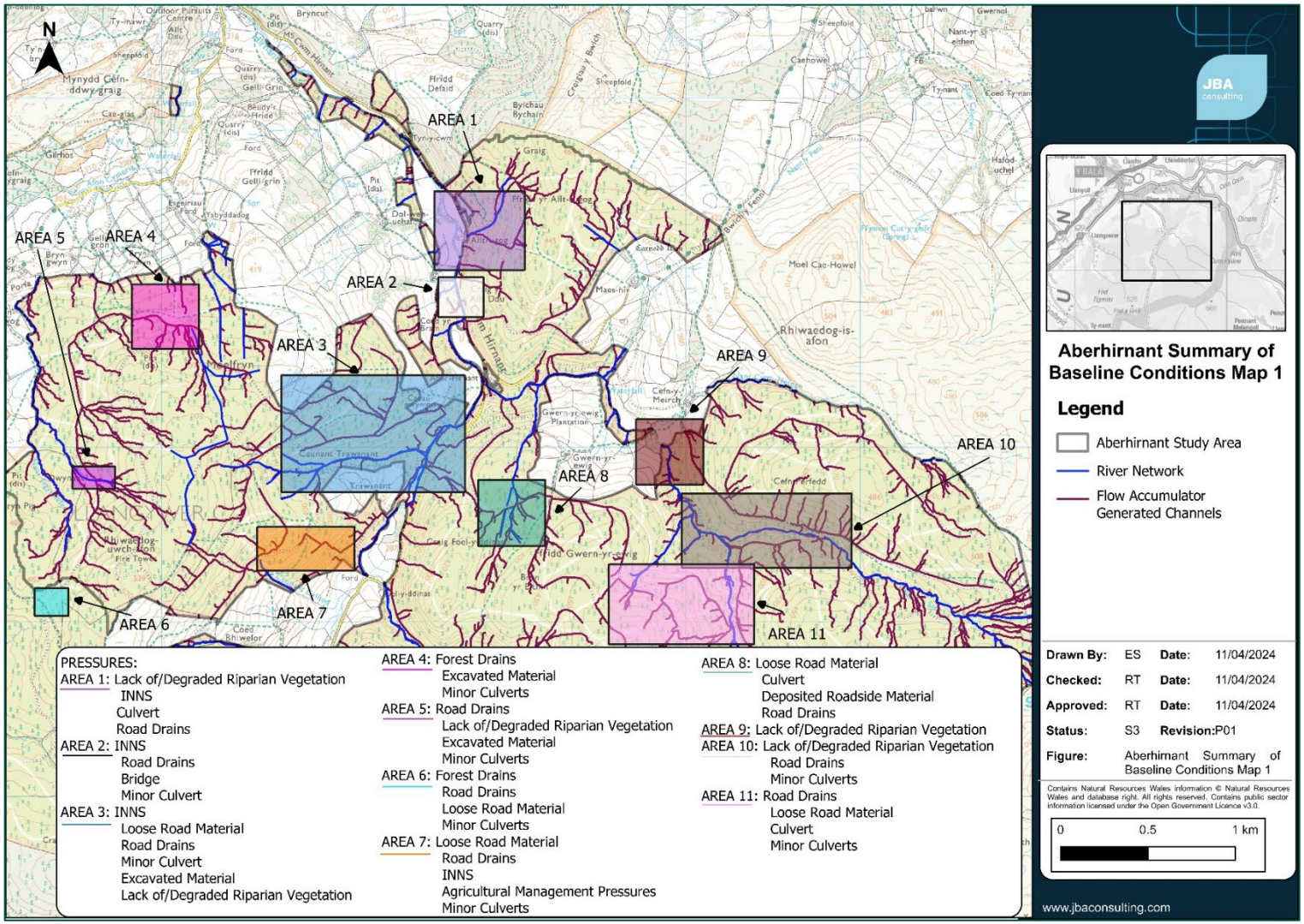

Figure 6-6: Summary of Baseline Conditions in northern Aberhirnant Forest

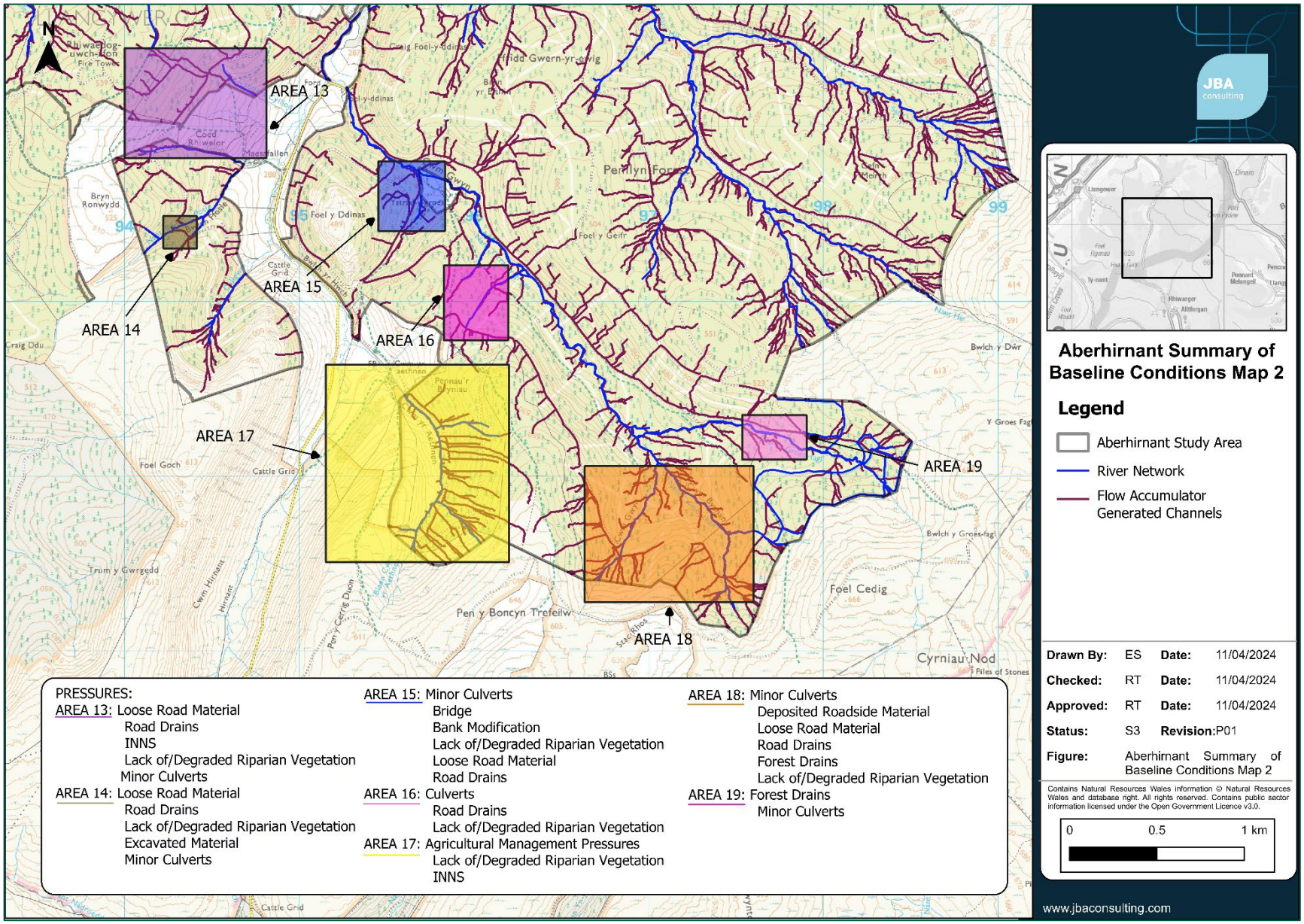

Figure 6-7: Summary of Baseline Conditions in southern Aberhirnant Forest

PRESSURES	KEY IMPACTS	Replace culverts with oversized box, or bottomless culverts or clear span bridges to facilitate fish passage	Reconnect streams with their floodplain or hillslopes using channel features to elevate flow to floodplain (e.g. woody material in watercourse or lowering banks where there is an opportunity to increase water transfer from river to floodplain)	Increase planting vegetation within riparian zone	Increase the width of the buffer zone to deliver multiple benefits and near main river to buffer from sediment and peak flows.	Add woody material to attenuate flows, improve natural functioning of the stream and create wet habitat by pushing water onto the riparian zone (if present) in higher flows. Includes brash and windrow.	Remove INNS	Leaky barriers may form naturally or be constructed across streams or drains. Leaky barriers are most effective if they are formed naturally and are placed / built in series.	Embed Sustainable Forest Management Practices.	Clear catch pits	Remove excavated material	Improved placement of roadside material	Add Catch Pit	Add bales or geomembrane to catch pits	Soft engineering	Add Micro Bund
Timing and practise of clearfell and thinning forest operations	Increased soil compaction from machinery. Increased runoff and sediment entrainment. Tree removal.			■	■			■	■						
Presence and hydrological connectivity of **road drains** to watercourses	Forces accumulation of sediment that can cause localised flooding, impactingt functionality of road for forest operations. Enhanced transfer of fine sediment into the watercourse network. Changes to flow conveyance during storm events and the potential to impact flooding mechanisms.					■		■		■			■	■	
Culverts in watercourses for road crossings	Restricted fish passage. Fine sediment input via overland flows from road crossings above. Scour of the bed downstream, disrupted sediment tranport and loss of longitudinal connectivity.	■													
Loose road material	Input of fine sediment/ pollutants into watercourse network, both direct (nearby roads) and indirect (sediment transport from drain network).									■			■	■	
Deposited roadside material	Potential for fine sediment/ pollutants to enter watercourse if entrained via overland flows.					■		■		■		■	■	■	
Lack of/ degraded riparian zone	Limited buffer between forestry operations and watercourse; enables pathway for pollutants. Reduced biodiversity. Loss of natural functioning in areas where riparian zones should be present. Lack of shading (no riparian vegetation) or overshading (non-native riparian woodland).		■	■	■	■									
INNS	Loss of native species.						■								

Figure 6-8: Pressures and opportunities matrix

Presence and hydrological connectivity of **forest drains** to watercourses	Potential loss of peat through lowered water table. Enable fine sediment transfer and increased flow conveyance. Increased pollutants may degrade downstream aquatic habitats in river network.																
Excavated material	Potential for fine sediment/ pollutants to enter watercourse if entrained via overland flows.																
Agricultural Management	Limited buffer between land use and watercourse; enables pathway for pollutants and sediment. Reduced biodiversity. Loss of natural functioning in areas where riparian zones should be present. Lack of shading (no riparian vegetation). Poaching of banks leading to overwidening and sediment input to river.																
Bank modification	Limited lateral erosion and or migration of the watercourse. Loss of bankside habitat. Loss of hydromorphological diversity. Can lead to acceleration of in-channel velocities																
Bridge	Limited lateral erosion and or migration of the watercourse. Loss of bankside habitat.																

Figure 6-9: Pressures and opportunities matrix

7. Opportunities

7.1 Overview

To meet the objectives of this study and improve the management of water, potential integrated catchment management opportunities have been identified across the Aberhirnant Forest. Options include local scale interventions that, if applied within priority areas, have the potential to benefit the broader scale geomorphic and ecological environment and improve water management. The flow and sediment attenuation options identified in this section are a direct response to the pressures identified, with the overall aim of managing the conveyance of water and sediment across Aberhirnant Forest study area, so that it is more aligned with natural processes.

An overview of each flow and sediment attenuation opportunity has been given below to provide a general insight into the purpose of each opportunity along with associated benefits and constraints.

Table 7-1: Key opportunities within Aberhirnant Forest

Key opportunity	Technique overview/benefits	Constraints
Embed Sustainable Forest Management practices Note this has not been mapped due to it being a forest-wide opportunity.	Where possible felling could occur across slope and windrow scattered in lines perpendicular to headwater streams/drainage channels to help intercept and attenuate overland surface water flow pathways. As a result, this will encourage a reduction in downslope flow velocities and deposition of fine sediment, preventing inputs to headwater streams and the Afon Hirnant downstream. The disconnection of forest and road drain and the establishment of intact riparian buffer strip would also help to reduce the input of sediments into the watercourses. Hand-felling could also be introduced near all headwater streams and the main river to minimise disturbance and the displacement of fine sediment. This would go above the industry standard recommendations to reduce disturbance and sediment input. Good supervision should lead to identification of areas that have excessive ground damage from machine travel. These areas should therefore be avoided to prevent further damage and sediment displacement. Vehicle movements for the purposes of cultivation and harvesting operations should aim to limit road sediment displacement and should avoid riparian areas. Could reduce the amount of traffic on roads and improve road conditions where many potholes are evident to reduce fine sediment entrainment. Would contribute to the 'Ensure compliance with the requirements of the Water Framework Directive when undertaking operational activities by following good practice as outlined in the 'UK Forest Standard - Forest and Water Guidelines' to protect water quality and freshwater ecosystems within the forest' FRP objective.	Felling across slope may be too dangerous on steep-sloping areas as gravitational forces combined with a high slope angle could cause machinery to topple. There will still be a release of fine sediment and displacement of road material. Therefore, machinery and haulage operations need to always follow best practice to reduce/minimise risk of sediment transport at all times. The balance between the health and safety requirements of using more mechanical felling and extraction needs to be considered against the potential impacts to the watercourses.

Key opportunity	Technique overview/benefits	Constraints
Add micro bund	Micro bunds (max crest height 10-50cm) can be implemented in small, shallow drainage channels, surface depressions and along overland flow pathways (e.g. along tracks/paths) throughout Aberhirnant Forest to intercept and store water in the landscape, as well as to encourage overtopping (during heavy rainfall events) onto adjacent slopes and floodplains. Can lead to the deposition and build-up of silt and decomposing natural material and subsequently providing habitat for plants and invertebrates. Higher amounts of infiltration can also be encouraged, resulting in reduced acidification. Opportunities for micro-bund creation include along the disused track at NGR SH 98692 30244 to intercept overland flow travelling from the open ground above, as well as within forest drains at NGR SH 93996 32828 to attenuate flow and sediment transport. Would contribute to the 'Ensure compliance with the requirements of the Water Framework Directive when undertaking operational activities by following good practice as outlined in the 'UK Forest Standard - Forest and Water Guidelines' to protect water quality and freshwater ecosystems within the forest' FRP objective.	Earth bund construction will cause a temporary disturbance to the surrounding land. There was relatively good access to areas where micro-bunds could be implemented. These areas were not surrounded by dense vegetation. It is likely that plant machinery will be able to construct in these areas. Will reduce the amount of water that is discharged into nearby headwater streams and the main Afon Hirnant during a heavy rainfall event. Periodic inspection would be required to ensure that each bund remains stable.
Culvert replacement	Culverts will ideally be removed where possible to improve the connectivity for fish populations, where this is infeasible, culverts being replaced with a clear span bridge or bottomless arch culvert set below bed level (>0.5m), as set out in the fish pass guidance is recommended.	The cost of the works would need to be weighed up with the benefits of opening up the watercourse. This will need to be informed by the undertaking of fish surveys up and down stream of the culverted sections to confirm fish presence or absence
Add catch pit	Catch pits should be excavated in areas where there is significant transportation of fine sediment. Excavating a new catch pit along a road drain will cause an increase in drain width and a subsequent reduction in flow velocity. As a result, this fine sediment will be deposited, reducing the amount that is transported downstream and into the main Afon Hirnant. Consideration should also be given to investigating and addressing the sediment source(s). Would contribute to the 'Ensure compliance with the requirements of the Water Framework Directive when undertaking operational activities by following good practice as outlined in the 'UK Forest Standard - Forest and Water Guidelines' to protect water quality and freshwater ecosystems within the forest' FRP objective.	Could lead to displacement of road material. There may be temporary disturbance to habitats when excavating the catch pit.

Key opportunity	Technique overview/benefits	Constraints
Clear catch pits NRW have implemented a large number of catch pits along road drains throughout the study area.	Removal of the fine sediment and material that has accumulated overtime within the excavated depression, will help to restore catch pit functioning. As a result, there will be a reduction in the amount of fine sediment that reaches watercourses, preventing degraded water quality. It has been acknowledged that the clearing out of catch pits is an element of general road maintenance; however, site observations identified a lack of ongoing maintenance, therefore a lot of the catch pits require clearing out. Would contribute to the 'Ensure compliance with the requirements of the Water Framework Directive when undertaking operational activities by following good practice as outlined in the 'UK Forest Standard - Forest and Water Guidelines' to protect water quality and freshwater ecosystems within the forest' FRP objective.	Requires regular inspection and long-term maintenance to ensure sufficient functioning. Carbon emissions associated with machinery needed for long-term maintenance.
Add bales or geomembrane to catch pits	Adding a haybale or geomembrane along the downstream side of a catch pit can be used to enhance processes associated with regular catch pit functioning and mitigate any sediment related pollution incidents. These materials can intercept greater quantities of flow, causing a greater reduction in flow velocity and encouraging more fine sediment deposition. As a result, there will be even less fine sediment transported downstream and into the main Afon Hirnant. This option is best placed at catch pits where there are significant fine sediment inputs. Would contribute to the 'Ensure compliance with the requirements of the Water Framework Directive when undertaking operational activities by following good practice as outlined in the 'UK Forest Standard - Forest and Water Guidelines' to protect water quality and freshwater ecosystems within the forest' FRP objective.	There may be temporary disturbance to habitats when installing materials. Haybales will degrade when wet, therefore there would need to be ongoing maintenance of this material to ensure that they are removed and replaced to prevent mobilisation, which could lead to a potential culvert blockage risk. Mechanised plant machinery may be required to remove and replace haybales.
Remove excavated material	Removal of deposited excavated material will prevent this sediment from being transported towards watercourses during heavy rainfall events, subsequently reducing the amount of fine sediment that is inputted into watercourses and improving water quality. Would contribute to the 'Ensure compliance with the requirements of the Water Framework Directive when undertaking operational activities by following good practice as outlined in the 'UK Forest Standard - Forest and Water Guidelines' to protect water quality and freshwater ecosystems within the forest' FRP objective.	Machinery will be required to remove mounded material which may result in temporary disturbances to habitats and the displacement of more fine material.

Key opportunity	Technique overview/benefits	Constraints
Improve placement of roadside material	Throughout the Forestry Block, it is common practice to import type 1 aggregate in bulk preparation for road maintenance operations, therefore this material will not be removed from the Forest. Focus should therefore investigate how to improve the storage of this material and to reduce run off from it, i.e., could store the material in a localised low spot in topography whilst making sure that it is not intercepting any overland flow pathways to reduce the amount of material that could be mobilised during a heavy rainfall event. As a result, this would reduce the amount of sediment that is transported towards headwater streams and the Afon Hirnant and improve water quality. Would contribute to the 'Ensure compliance with the requirements of the Water Framework Directive when undertaking operational activities by following good practice as outlined in the 'UK Forest Standard - Forest and Water Guidelines' to protect water quality and freshwater ecosystems within the forest' FRP objective.	As LiDAR does not penetrate vegetation in densely covered areas well, such as in Aberhirnant Forest, then the underlying land surface topography may not have been accurately picked up. Therefore, identified localised low spots in topography will have to be ground truthed.

Key opportunity	Technique overview/benefits	Constraints
Bank lowering (lowering sections of watercourse bank)	Encouraging water to flow onto the local floodplain where it can be slowed and temporarily stored means that the floodplain habitats will become wetter. This will encourage the development and enhancement of wetland habitats, such as wet woodland, if species such as Alder and Willow were allowed to develop. Creating wetter floodplains areas will help to reduce the risk of drought and wildfires within these parts of the study area. There are two opportunities to implement this within the study area. The first location is along a drainage ditch found at NGR SH 97739 29172 to encourage flow dispersion along the left bank slope to increase wetland areas and attenuate flow, as flow is currently confined to the linear feature and as a result, the ditch is very incised. The second location is at NGR SH 95623 30430, where multiple bank areas could be lowered to encourage more multithread flow routes over this area of land. The right-side seems quite well connected but the left is very dry and flow routes confined to the drainage channels. There is the opportunity to go above the industry standards by reconnecting the floodplain to the watercourses.	Lowering the watercourse bank requires physical manipulation to riparian and bankside habitats, which can be temporarily damaging to macrophytes, fish and aquatic invertebrates if not carried out with appropriate mitigation, such as silt and pollution prevention measures. The terrestrial habitats recorded around the first area of proposed interventions were largely widespread in the areas of existing plantation, with the habitats dominated by conifers with mosses covering the first floor. The habitats present at the second location, were characteristic of species which can tolerate wetter conditions, with Soft Rush, Silver Birch, and mosses present, with Heather present in the drier patches. The works would likely result in the permanent loss of some of the moss-covered forest floor at the first site as it transitioned to wetter communities. However, the floodplain reconnection will increase the diversity of wetland habitats present across the forest area and is anticipated to lead to supporting an increased species diversity , especially when combined with other opportunities such as increasing the size of riparian zones along the watercourses. There are limited opportunities to implement this elsewhere, apart from in places identified, as a lot of the headwater streams are largely incised, and bedrock lined.

Key opportunity	Technique overview/benefits	Constraints
Add woody material • Large windrow • Leaky barriers (stacked across the channel, or in a lattice formation) • Heather bundles • Root wads	Depending on its positioning in a channel, woody material (including heather bundles, windrow, root wads and large tree/trunk pieces) can be used to help hold water upstream to delay the rise to a flood peak downstream; to divert water onto the floodplain to increase floodplain connectivity and to encourage/enhance geomorphic processes such as scour and deposition to create localised diversity in flow dynamics and sediment transport. As a result of implementing woody material to encourage overtopping and the enhancement/creation of wetland areas, the risk of drought and wildfires will be reduced as water will be retained for much longer in the riparian and local floodplains within the study area. Woody material can create a variation in flow types and increase the extent of shelter for fish and conditions for aquatic and saprophytic invertebrates providing habitat. Fine sediment (displaced by felling practices) will also be trapped by woody material that is fixed across the channel, improving water quality and dissolved oxygen levels to support native wildlife. A lot of material used can be sourced from site such as root bowls. These were in excess in sub-catchment 2 due to recent felling. Would contribute to the 'Ensure compliance with the requirements of the Water Framework Directive when undertaking operational activities by following good practice as outlined in the 'UK Forest Standard - Forest and Water Guidelines' to protect water quality and freshwater ecosystems within the forest' FRP objective. This opportunity agrees with recommendations outlined in the UK Forestry Standards (2023).	Introducing large woody material to the channel could trigger some erosion, although the extent of this will be determined by the composition of the bed and banks. Woody materials could become dislodged in high flows or may require 'topping up' in a few years when the wood has decomposed or washed downstream. Would need continued inspection to ensure sufficient functioning, especially after a large storm event as this is where woody material could get displaced and mobilised downstream and cause blockages at culverts. It is best practice to only install leaky barriers in watercourses that are less than 5m wide UK Forestry Standard Practice Guide (2022)[1] and CIRIA NFM Manual (2022). The size of the woody material used in channels should be considered before their implementation. Smaller woody material will decompose quicker than bigger material. Fresh brash, if used, could supply a significant source of phosphate to the headwater streams and main river (Afon Hirnant).

[1] UK Forestry Standard Practice Guide (2022) *Designing and managing forests and woodlands to reduce flood risk*. Forestry Commission Practice Guide.

Key opportunity	Technique overview/benefits	Constraints
Increase native riparian vegetation	Introducing locally native riparian tree and scrub species (such as species already noted on site including Willow, Downy Birch, Silver Birch, Alder *Alnus glutinosa*) or by creating a buffer to allow natural regeneration of species and marginal vegetation along the banks of a channel/pond can be beneficial. Additionally, enhancing existing riparian buffer zones can help to intercept overland flow and rainfall, slowing flow as it moves towards a body of water. Marginal and bankside vegetation can help to filter out pollutants from agricultural and felling surface run-off, resulting in water quality improvement which is beneficial to the biota of the river. The more dappled shading provided by broadleaved species in contrast with conifer species, is likely to provide benefits by allowing more macrophytes to establish in the watercourse which would have knock-on benefits upon water quality and fauna. UK Forestry Standards (2019) identify a riparian buffer zone width of 2-10m for watercourses that have a width of less than 2m. A riparian buffer zone width of 2-20m is suitable for a watercourse with a width greater than $2m^2$. There is the opportunity to go beyond these standards by implementing larger buffer zones along watercourses in and adjacent to the site, such as along the main tributaries in the forestry and along Afon Hirnant. Implementing a wide riparian buffer zone will help to mitigate wildfire risks within the study area. Would contribute to the following FRP objectives: • Improve the internal structure of the forest by developing age class diversity, variation of tree sizes and mixtures of species within stands. • Diversify woodland types within the forest, by increasing the variety of coniferous woodland and the expansion of native and riparian woodland habitats, which will help to improve connectivity within the forest and provide opportunities for linking to woodland networks outside of the forest in Cwm Hirnant and around Bala Lake. • Create a diverse permanent forest structure and ecosystem that includes riparian and native woodland, natural reserves and long-term retentions, with more successional woodland and open habitats along forest roads and rides where natural processes can take place. • Expand the existing riparian woodland network to provide better buffering against harvesting operations and to help improve the water quality in freshwater ecosystems. • Improve the visual and sensory and landscape habitat value of the forest by increasing native woodland along the Hirnant and Glyn Valleys.	Adversely, disturbing the soil when planting riparian vegetation could cause the loss of or damage to existing sensitive species. Increasing shade levels along areas of watercourse may impact marginal/ground level vegetation and result in alterations to the current vegetation communities. However, these alterations are likely to be beneficial due to dappled shading allowing macrophytes to establish in the watercourses.

Key opportunity	Technique overview/benefits	Constraints
INNS control	Programmes for the long-term control and eradication of invasive species such as Rhododendron should be designed to be implemented. To prevent INNS re-establishing from local source areas, management in the wider area will be required. Would contribute to the following FRP objectives: • Improve the internal structure of the forest by developing age class diversity, variation of tree sizes and mixtures of species within stands. • Diversify woodland types within the forest, by increasing the variety of coniferous woodland and the expansion of native and riparian woodland habitats, which will help to improve connectivity within the forest and provide opportunities for linking to woodland networks outside of the forest in Cwm Hirnant and around Bala Lake. • Create a diverse permanent forest structure and ecosystem that includes riparian and native woodland, natural reserves and long-term retentions, with more successional woodland and open habitats along forest roads and rides where natural processes can take place. • Expand the existing riparian woodland network to provide better buffering against harvesting operations and to help improve the water quality in freshwater ecosystems. • Improve the visual and sensory and landscape habitat value of the forest by increasing native woodland along the Hirnant and Glyn Valleys. This opportunity also agrees with recommendations outlined in the UK Forestry Standards (2023).	Long-term maintenance will be required to prevent re-establishment. In the short-term removal of Rhododendron may result in erosion of soils and mobilisation of finer materials due to bare ground underneath the dense stands.

[2] Forestry Commission (2019) *Managing forest operations to protect the water environment*. Forestry Commission Practice Guide. Forestry Commission, Edinburgh. I-iv + 1-48pp.

Key opportunity	Technique overview/benefits	Constraints
Add boulders	Boulders can be placed in channels to intercept flow and cause a reduction in flow velocity, delaying the rise to flood peak downstream. Boulders can also help to divert water onto the floodplain to increase floodplain connectivity and to encourage/enhance geomorphic processes such as scour and deposition to create localised diversity in flow dynamics and sediment transport. There is an option to scatter boulders within the headwater stream at NGR SH 97253 31006. This watercourse is fast flowing and dominated by bedrock, therefore the boulders will act to 'brake' flow and create roughness, encouraging flow and sediment transport attenuation. The boulders will also help to increase habitat available for aquatic invertebrates and fish.	Steep slopes confine the identified opportunity site, therefore access for plant machinery is limited to bring boulders on site. Size and quantity of boulders are currently indicative, therefore there would need to be considerations regarding the actual design at detailed design stage.
Open ground creation Note this has not been mapped due to it being a forest-wide opportunity.	The creation of areas of openings within the forestry plantation can increase the diversity of habitats and provide opportunities for a wider number of species (Forestry Commission (2014). Research has shown areas of open ground can be beneficial for a number of species, including for certain birds, invertebrates, reptiles and flora (Anderson, 2003). When deciding the location and type of open land, identification of which priority species are to be the focus of the enhancements is required, the habitat preferences of the target species should then be taken into account, along with ecological connectivity to other habitats and existing populations. Due to the species records and the surrounding habitat, priority species which may benefit by the inclusion of open ground at Aberhirnant include reptiles such as Common Lizard, which may benefit by increased areas for basking and Nightjar. This opportunity agrees with recommendations outlined in the UK Forestry Standards (2023).	The creation of open ground in areas of existing forestry would result in the loss of some existing habitats. However, it would increase the diversity of habitats present in the forestry and provide habitat for additional species. In order to keep areas of ground 'open' ongoing management is likely to be required.

Key opportunity	Technique overview/benefits	Constraints
Soft engineering Note this has not been mapped as no suitable locations were identified during the site walkover, however there may be opportunities to implement this measure in other parts of Aberhirnant Forest that were not visited.	The removal or replacement of hard engineering structures on the watercourses, such as concrete reinforcement and gabion baskets, could improve the geomorphology of the channels as well as restore lateral connectivity.	The impact or removal of hard engineering could result in alterations to the channel processes and trigger some erosion, although the extent of this will be determined by the composition of the bed and banks. Soft engineering is not suitable at the location where bank modification (i.e. gabion baskets) was identified as removing them could negatively affect the structural integrity of the adjacent bridge.

7.1.1 Prioritisation

It is recommended that opportunities are initially implemented in clear felled areas, as this is where the immediate issues with sediment transport and siltation will be occurring. In areas to be felled, it is important to have an idea of the interventions that could be implemented once felling has taken place. However, there may need to be a review of these options as the process of felling could reveal other watercourse characteristics or topographical modifications, e.g. small forestry drains, where further opportunities could be identified.

It will be more sustainable to prioritise the management of sediment sources throughout the study area, instead of implementing options that will rely on long-term maintenance and removal such as catch pits, as this could result in significant carbon emissions being generated due to machinery use.

It would also be beneficial to prioritise implementing opportunities within the larger sub-catchments such as sub-catchment 1, where a large number of options were identified. Targeting these bigger areas will result in a greater benefit to the management of water and sediment transport throughout the study area, whilst also providing a wider range of environmental benefits.

Any culvert removal or modification carried out with an aim to improve fish passage should take place from the culverts located closest to the Afon Hrinant before proceeding to culverts further upstream, to ensure connectivity is achieved and should be carried out on the main tributaries first. Therefore, the culverts lower down the site should be prioritised for modification or removal.

Options involving the placement of natural material across headwater streams to increase flow heterogeneity are considered to be 'low risk' proposals according to NRW's Low Risk Impoundment Position Statement (Natural Resources Wales, 2024). Low risk proposals do not require a licence application. It is important that the design of the options does not cause detriment to the environment, water uses and protected rights during the planning phase.

Opportunities identified across the whole of the Aberhirnant Forest study area have been mapped in Figure 7-1 and Figure 7-2. To show examples of site-specific opportunities, four focus area scale maps have been created to aid understanding and rationale behind suggested opportunities (see Figure 7-3, Figure 7-4, Figure 7-5, Figure 7-6 and Figure 7-7).

7.1.2 Indicative costings of 'slow the flow' measures

Derived from: Highways England – Natural Flood Management: Design Specification Catalogue (2021).

- ***Leaky barriers*** – if made of wood, the typical cost will be £500-£2,000 per barrier. This includes equipment, materials and time. This excludes design, planning and consenting. They typically have a 5-10 year design life. The proximity of appropriate wood/timber material to use at each location will influence the unit cost.

- ***Offline storage areas and scrapes*** – the typical cost will be £10-£50 per m^3 of earth excavation. This includes equipment, labour and materials. This excludes design, planning, consenting and any requirements to spread or remove spoil. They typically have a design life of 10 years.
- ***Flowpath bund*** – the typical cost will be £50-£150 per linear metre of earthen bund. This includes equipment and materials. This excludes design, planning and consenting. They typically have a design life of 30 years.

All measures would require periodic inspections and maintenance to ensure continued structural integrity and functionality, preferably every 6-12 months and after any significant storm events.

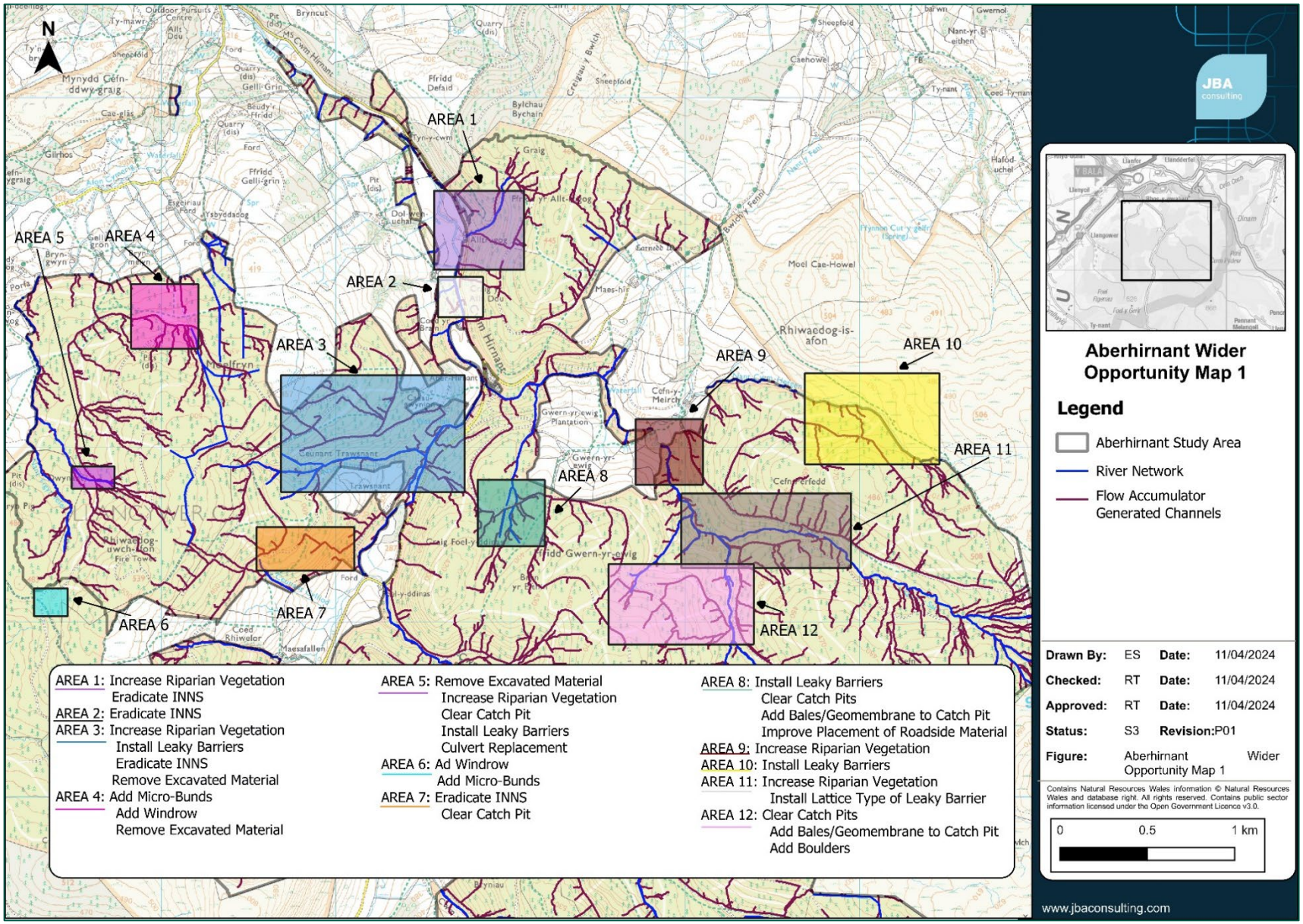

Figure 7-1: Wider Opportunities Map across northern Aberhirnant Forest

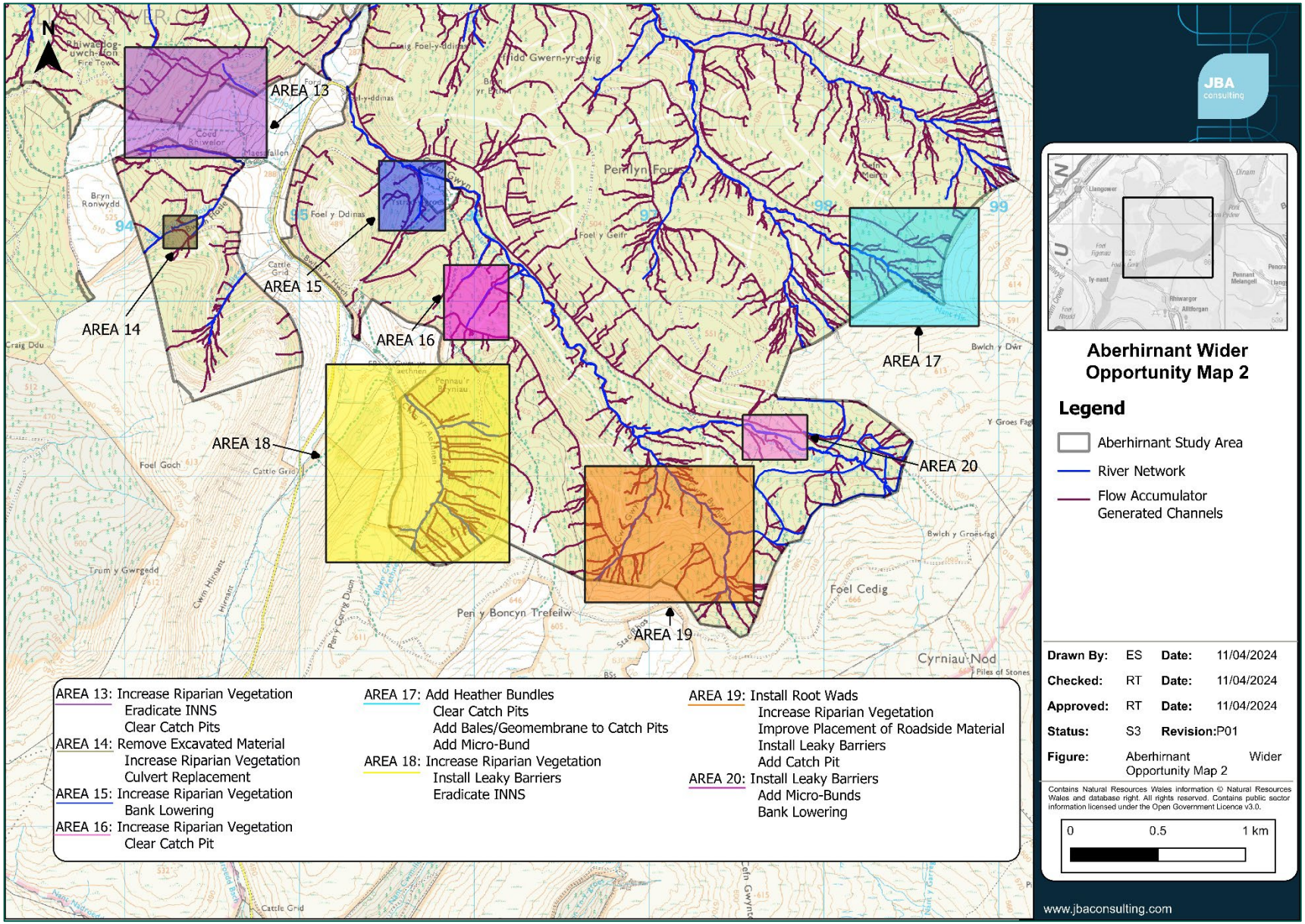

Figure 7-2: Wider Opportunities Map across southern Aberhirnant Forest

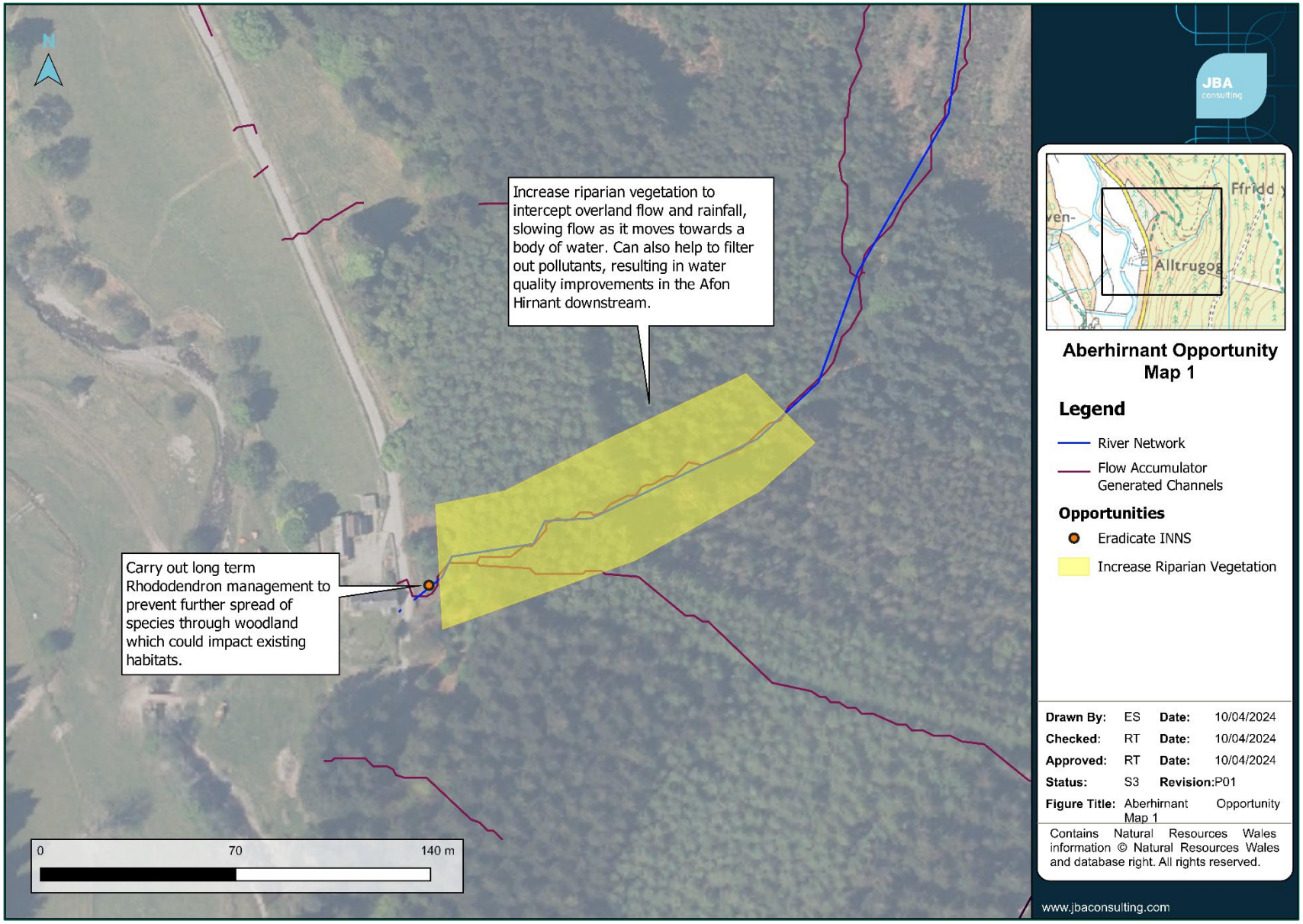

Figure 7-3: Opportunities identified at NGR: SH 95811 33241 (Sub-Catchment 5, Area 1 in Wider Opportunity Map

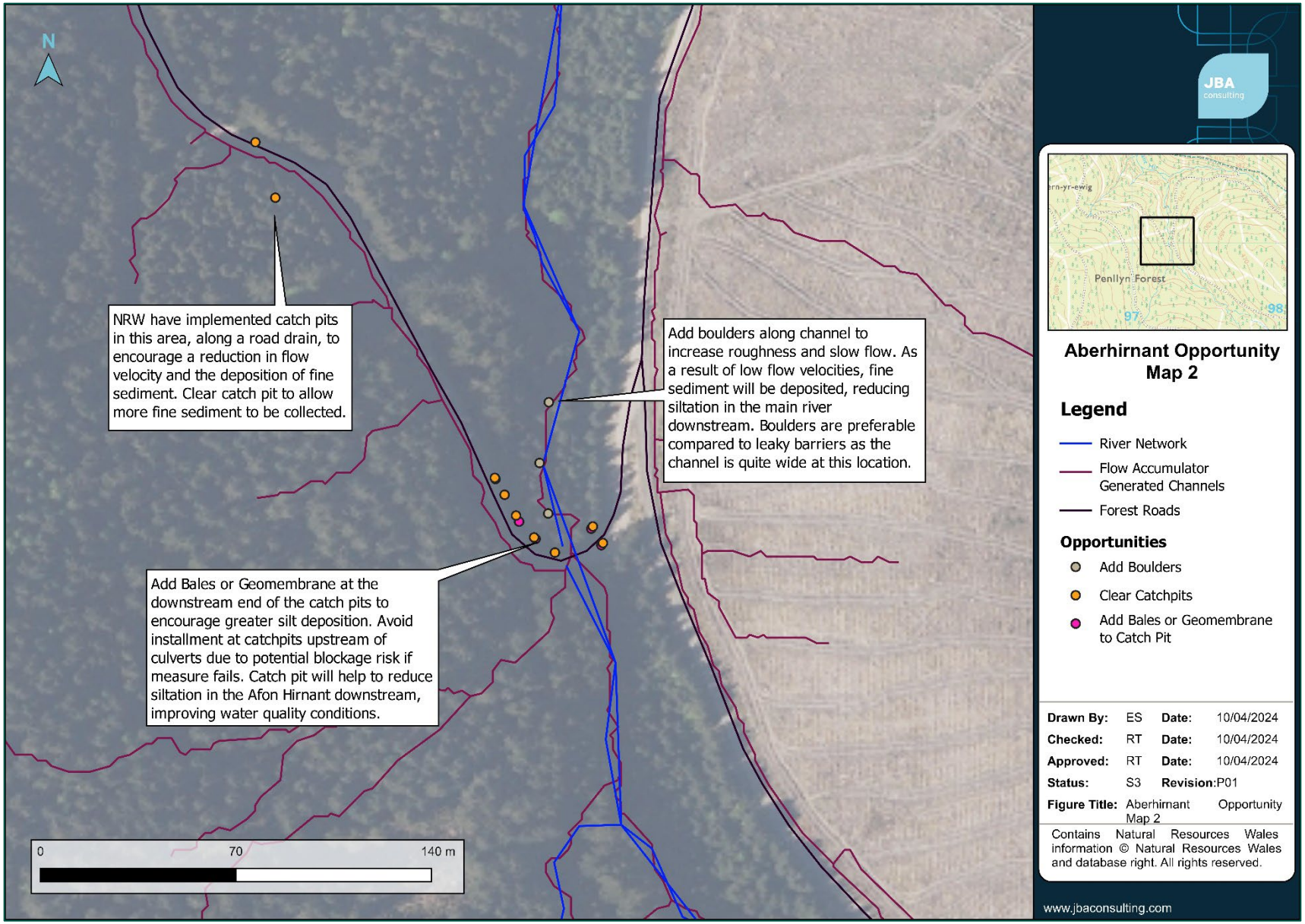

Figure 7-4: Opportunities identified at NGR: SH 97252 30999 (Sub-Catchment 1, Area 12 in Wider Opportunity Map

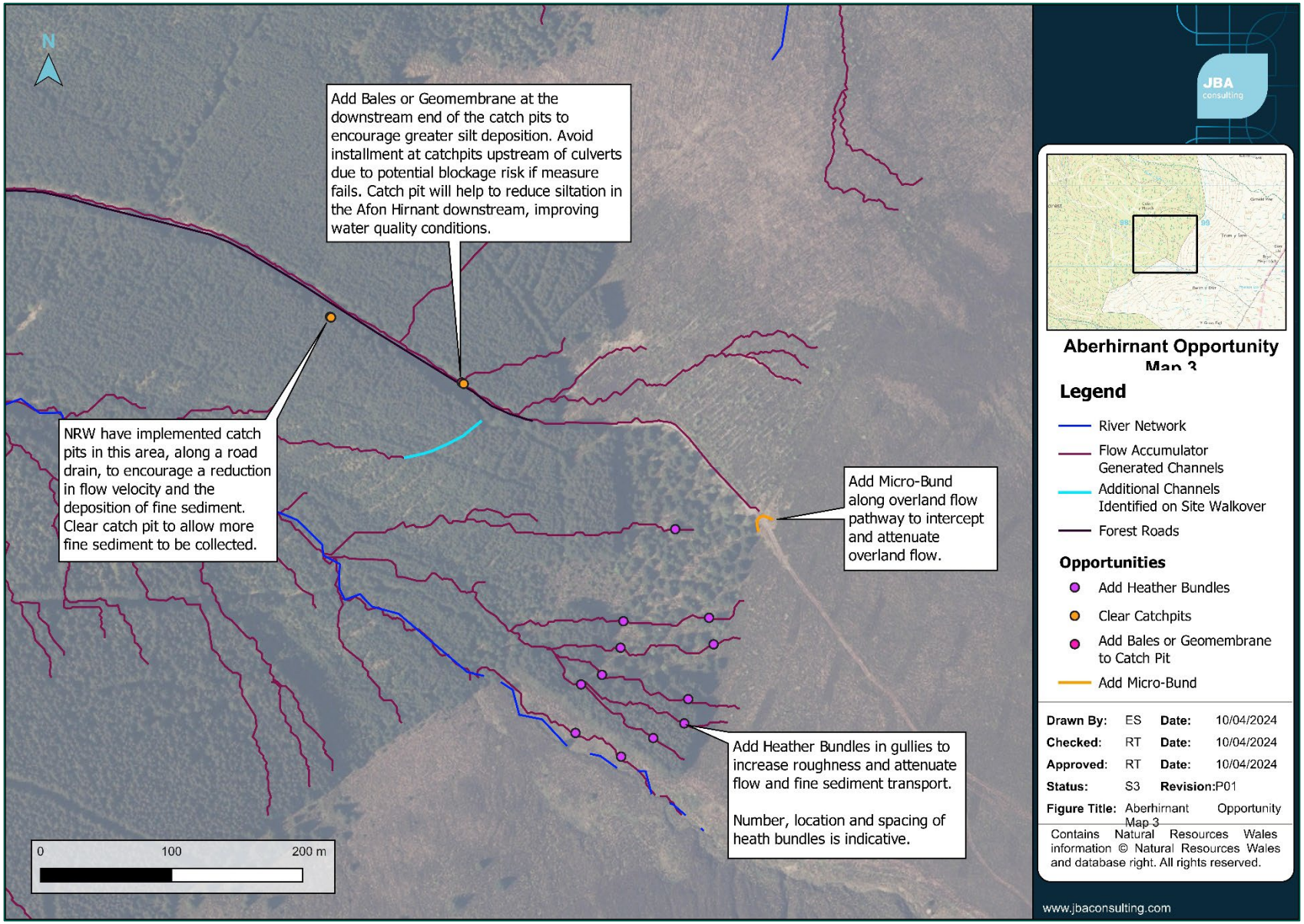

Figure 7-5: Opportunities identified at NGR: SH 98525 30274 (Sub-Catchment 1, Area 17 in Wider Opportunity Map)

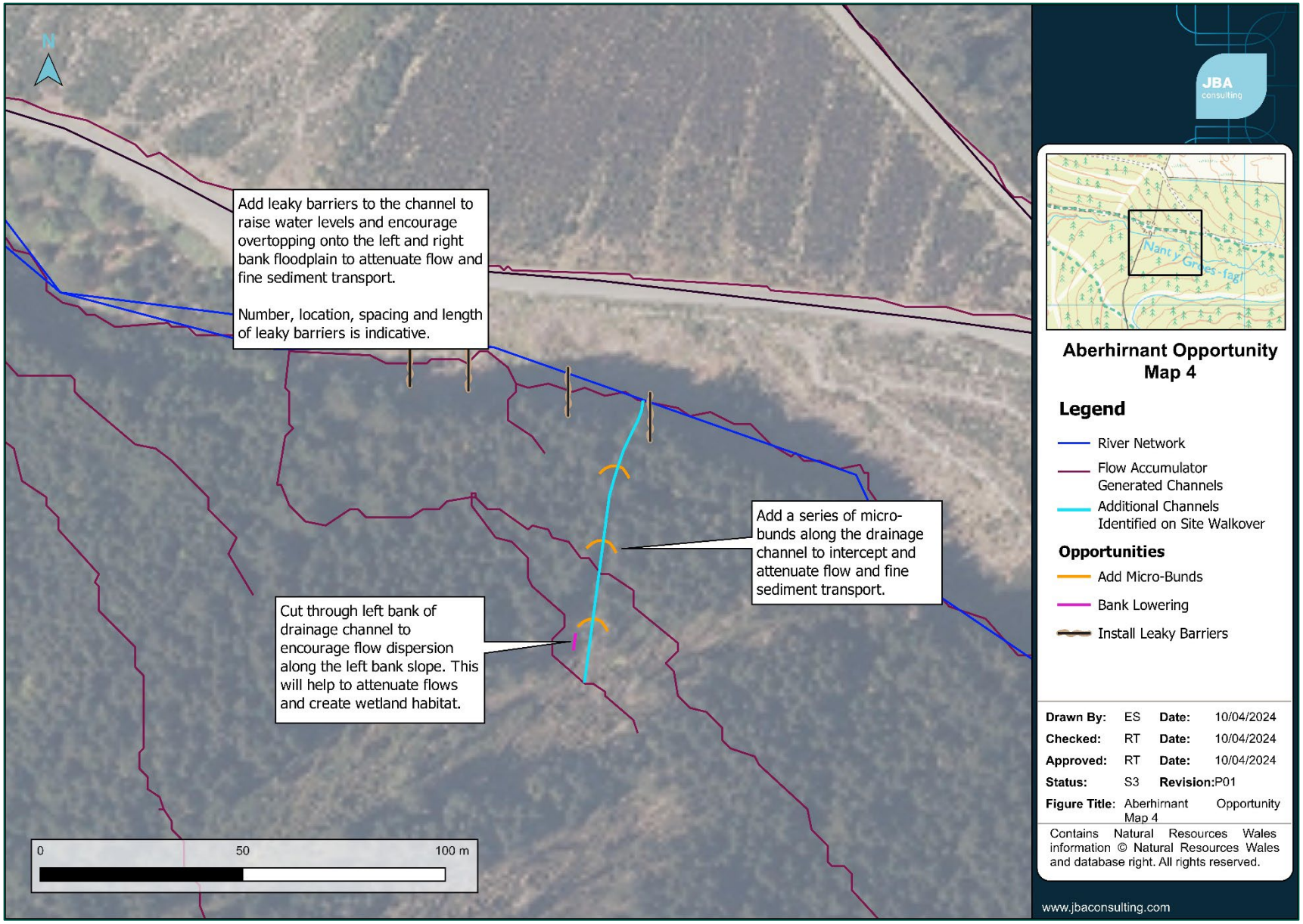

Figure 7-6: Opportunities identified at NGR SH 97745 29211 (Sub-Catchment 2, Area 20 in Wider Opportunity Map)

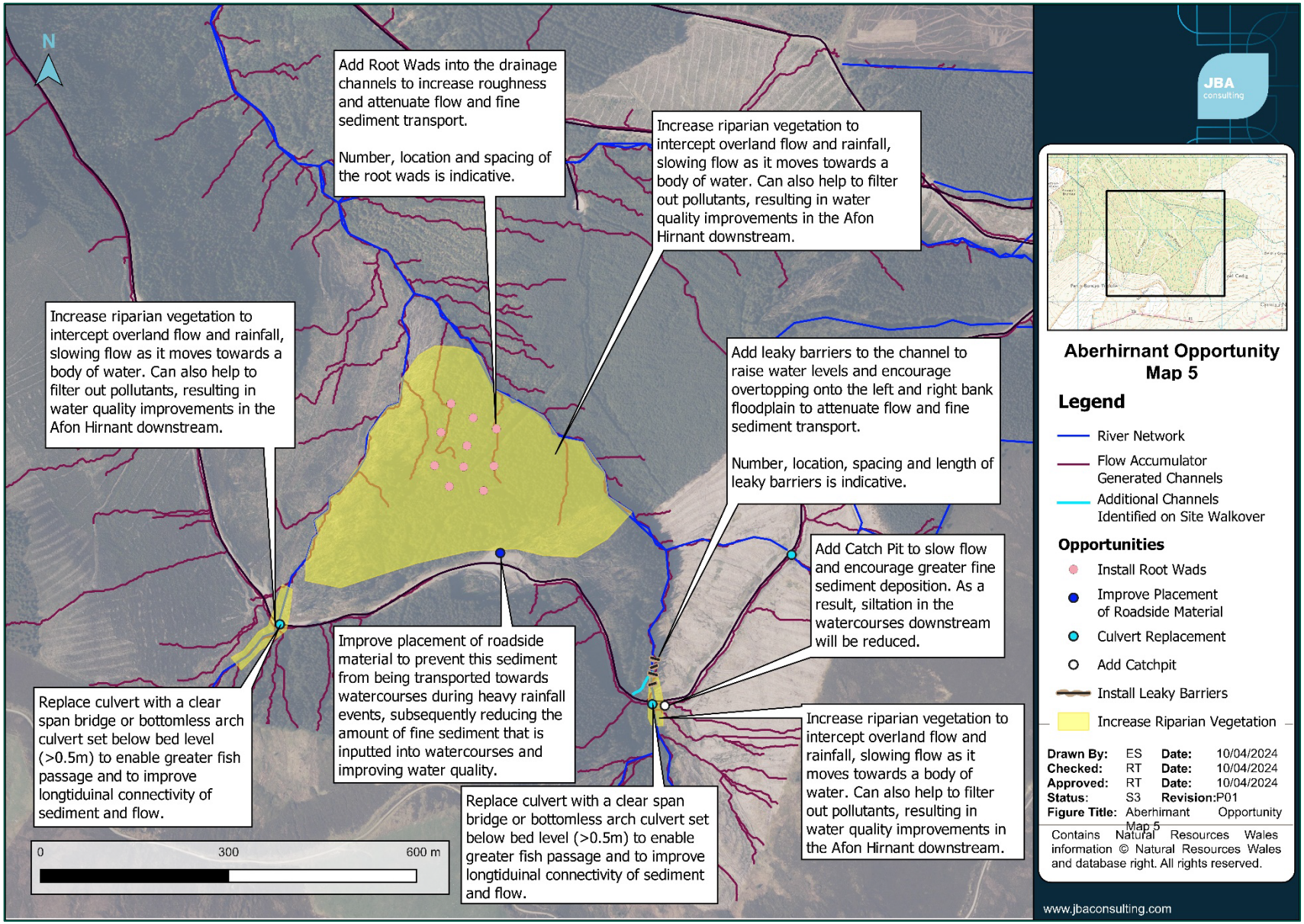

Figure 7-7: Opportunities identified at NGR: SH 97170 28707 (Sub-Catchment 2, Area 19)

7.2 Limitations

Due to the large Aberhirnant Forest study area (1,736ha), JBA were not able to survey all priority areas. Opportunities identified in surveyed areas could be assumed to work in non-surveyed areas that exhibit similar physical characteristics; however, these areas would still need ground truthing as constraints such as public footpaths, electrical pylons and fencing could prevent implementation. Opportunities could not be generated for areas that were particularly steep (i.e. greater than about 15%) as access and feature implementation would be too dangerous. Options should as leaky barriers should also not be installed in close proximity to culverts and bridges to reduce blockage and destruction risk during heavy rainfall/storm events. The most downstream barrier (those closest to structures) should be the most robust so that it can catch any debris that has been washed out from barriers further upstream (CIRIA, 2022).

Due to the scope of the survey, which was completed by carrying out rapid assessments at spot locations, a comprehensive ecological species list was not able to be produced and detailed habitat mapping was not undertaken. However, a general ecological overview of the site was achieved.

As a result of the dense tree cover within the study area, there was interference with the georeferencing of some photos taken using the GISMapp application. Subsequently, this will have affected the locational accuracy of the pressure and opportunity mapping within certain locations. Therefore, ground truthing is recommended before any feature implementation.

8. Conclusions

8.1 Summary

A desk-based and targeted, site-based geomorphological and ecological assessment has been undertaken to understand in more detail the current conditions within Aberhirnant Forest. The assessment included surveying headwater streams, forest drainage channels, forest roads and road drains and open ground within identified priority areas and recording any processes and pressures controlling flow and sediment dynamics and ecological habitats within the system.

This understanding of existing baseline conditions alongside the identification and assessment of physical pressures on watercourses within the study area has allowed a plan for water and sediment attenuation across Aberhirnant Forest to be developed in order to meet project aims and objectives. The options for water and sediment attenuation proposed will need to be further refined through future feasibility and design work prior to any implementation on the ground.

This report is part of a wider programme to implement integrated catchment management in other forestry blocks across the Welsh Government Woodland Estate (WGWE)

Key pressures on the water environment	Description
Timing of clearfell and thinning forest operations	Felling practices with the use of heavy machinery can cause ground disturbances, resulting in fine sediment displacement, compaction of soils leading to reduced porosity and a release of phosphate and nitrogen compounds that deplete water quality through acidification.
Bank modification	Installing hard engineering, such as gabion baskets, limit the lateral erosion and or migration of the watercourse and results in a loss of bankside habitat.
Invasive Non-Native Species	The presence of INNS could result in it spreading within the woodland and surrounding area. This would alter the habitats and composition of species present within the woodland.

Key pressures on the water environment	Description
Agricultural management pressures	Intensive grazing prevents the growth of a riparian vegetation. As a result, there is no buffer zone to filter out nutrients in water before it is discharged into streams and the main river, therefore water depleting water quality. Agricultural practices can also lead to increase acidification within the Afon Hirnant and fine sediment release.
Bridges	Installing a structure that spans a section of channel can result in direct habitat loss, acceleration in in-channel velocities and increase scour around the bridge abutments, encouraging the release of in-channel sediment.
Lack of/degraded Riparian Vegetation	Riparian vegetation, with a mix of broadleaf native trees, shrubs and grasses, creates an important transition zone between aquatic and terrestrial environments. Riparian woodlands are crucial for controlling erosion, improving water quality, providing habitat for wildlife, and supporting the food chain for aquatic ecosystems. Without riparian vegetation, polluted runoff from forestry operations can enter the watercourse directly, leading to acidic, polluted, and degraded water quality due to the lack of filtering capacity.
Road Drains	Forestry roadside drains artificially concentrate and accelerate water draining from large sloping areas of woodland. These drains are often connected to streams and rivers and can lead to increased downstream flood risk and degradation of water quality from fine sediment dispersal.
Deposited Roadside Material	During heavy rainfall events some of this deposited sediment could be remobilised and re-enter and watercourse and the main river resulting in decreases in water quality and increased water turbidity.
Excavated Material	During heavy rainfall events some of this excavated material could be remobilised and re-enter and watercourse and the main river resulting in decreases in water quality and increased water turbidity.

Key pressures on the water environment	Description
Culverts	Replacing a section of open channel with culverted sections can result in a direct loss of habitat and a lack of longitudinal and lateral connectivity.
Loose Road Material	Fine sediment inputs into headwater streams and drainage channels can result in decreases in water quality and increased water turbidity.
Forest Drains and Ditches	Forest drains contribute to a quicker conveyance of flow and sediment transport downslope, towards the main river. Can result in increased in-channel water levels and an increased risk of flooding downstream.

Potential opportunities to meet project objectives

- Embed Sustainable Forest practices
- Improve placement of roadside material
- Remove excavated material
- Clear catchpit
- Add catchpit
- Eradicate INNS
- Bank lowering
- Install root wads
- Add heath bundles
- Micro bund
- Add boulder
- Add large woody material/leaky barriers
- Add bales or geomembrane
- Increase riparian vegetation

Below are additional opportunities that could be implemented within the study area that would also align with project objectives. These opportunities have not been included within the larger opportunity table as there were no suitable locations found for these features during the site visit.

Additional opportunities

- Plan forest operations at catchment scale
- Produce catchment water management plans
- Implementation of J-shaped drains

8.2 Recommendations and next steps

All the opportunities identified during the course of this project have been reviewed within the context of the objectives defined in the Forest Resource Plan (FRP) for the Aberhirnant Forest. In addition, the opportunities will need to be reviewed with respect to wider NRW policies and plans including the Salmon and Sea Trout Plan of Action. Many of the opportunities correspond with actions outlined in the Powys Nature Recovery Action Plan. Some further surveys and investigations may need to be carried out before certain options can be progressed (e.g. ground investigations, contaminated land surveys, archaeological assessments etc.) and certain consents/licences may need to be sought depending on the design stage and the option being considered (e.g. flood risk activity permits, ordinary watercourse consents, protected species licencing, Habitats Regulations Assessment, planning permission etc.).

In addition, due to the lack of data points for fishery records within the site, it is recommended electro-fishing surveys are undertaken on more of the watercourses on the site that are connected to the river network to better understand the spread of species in the area. Any culvert removal or modification to improve fish passage should take place from the bottom of the site (closest to the Afon Hirnant) upstream, to ensure connectivity is achieved.

Observations about road drains, especially their connectivity (to watercourses) and condition, were common throughout the site visit, indicating a need to ensure the continued application of good practice. According to the UKFS (2023): “Forest drainage (including road drains) should be planned and, where necessary, existing drains should be realigned and disconnected from waterbodies to ensure that water is discharged before the edge of a buffer area, and never directly into a waterbody.” In addition, Forestry Commission Operations Note 25 (2011) states that “road drains should not discharge directly into watercourses. Road drains on the upper side of the running surface should use cut off or relief culverts to direct water to the lower side of the track a short distance before any stream crossings. Water from any road drain that carries a high sediment loads must be discharged into a buffer area of adequate size, or into a silt trap or catch pit that have been constructed to allow sediment to settle out before it enters the watercourse.“

No enhancement or restoration actions should be undertaken without refinement through future feasibility work and/or design. Any actions should not negatively impact the conservation objectives of the designated sites that are adjacent or within close proximity to, such as Berwyn SSSI or Chwarel Cwm Hirnant SSSI. Furthermore, habitats of principal importance should be retained as a priority, ensuring no net loss, along with species and habitats that support them that are listed on Section 7 of on the Environment (Wales) Act.

An identification and assessment of local constraints is required, and all interventions will require consultation with local stakeholders (e.g. tenants, farmers, graziers, etc.) prior to construction. This could be easier if the enhancement can be implemented by local people and stakeholders. Some measures will require design and construction to be implemented together will a long term management and maintenance plan, but others can be done locally, such as riparian planting.

We understand that it is the intention of NRW to apply the principles of the site survey methodology, including the completion of the simplified inventory list, to other WGWE locations in the future. A version of the MS Excel inventory list was developed and

implemented into an in-house data collection app (GISMapp), loaded onto a rugged tablet device, that allowed all the point/area-based data (including metrics, descriptions, opportunities, constraints and photos) to be recorded, georeferenced and securely stored during the site visits. For the initial trial application of this assessment method there were three specialist staff out on site together covering the topics of NFM, geomorphology and ecology, all informed by the pre-visit desk-based assessments. This allowed the data collection, opportunity, actions and constraints identification to benefit from the combined skills and experience of three individuals, both during the on-site discussions and the subsequent interpretation and reporting tasks.

The application and availability of three individual specialists might not be possible for all further surveys of this type across the wider WGWE going forwards. However, it should be possible for the completion of the inventory list, together with the capture of a comprehensive set of point/area photos all suitably georeferenced, to be undertaken by a pair of operatives (to address lone working risks in remote areas) suitably informed about the objectives of the work, skilled in one or two of the key disciplines, and who also have a reasonable knowledge of the other discipline(s). This should allow the identification of a good set of potential NFM/restoration opportunities and possible constraints to take place during a site visit. The subsequent interpretation of the data captured, together with the photo record, can then be reviewed by the site operatives taking advice from appropriate NRW specialists in order to determine an agreed set of potential opportunities and actions for the point/areas in question for consideration by the relevant NRW forestry management and operational staff.

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Appendices

Data Archive Appendix

Data outputs associated with this project are archived in NRW's Document Management System and shapefiles are stored on X drive.

The data archive contains:

[A] The final report in Microsoft Word and Adobe PDF formats.

[B] An excel spreadsheet of Aberhirnant Water Management Strategy and Delivery Plan Table

[C] A series of GIS layers on which the maps in the report are based with a series of word documents detailing the data processing and structure of the GIS layers. These are archived in x:\\Resource Management\River Restoration

[D] A full set of images produced in jpg format.

Metadata for this project is publicly accessible through Natural Resources Wales' Data Discovery Service https://metadata.naturalresources.wales/geonetwork/srv (English version) and https://metadata.cyfoethnaturiol.cymru/geonetwork/cym/ (Welsh Version). The metadata is held as record no NRW_DS161384.

Further copies of this report are available from enquiries@cyfoethnaturiolcymru.gov.uk

Appendix A. Inventory list

Proposed inventory and methodology for site/reach/area information

Sub-catchment	Feature type	Frequency of survey/ collection notes	Characteristic	Drop down value - Y/ N	Things to include in drop-down box	Larger text box - Y/N	Examples/ more information
Sub-catchment 01, 02, 03 etc	Forest Roads	Spot check. To be surveyed from the car or on foot on route to and from sub-catchment headwaters. New entry to be made if conditions change.	Road surface/ condition/ presence of vegetation	N		Y	Describe the road surface and physical character, include whether any vegetation is present
			Evidence of road erosion (overbanking) or hillslope erosion; if yes, could flow dispersal options be considered?	N		Y	Caused by the physical characteristics of the road. Flow dispersal interventions could include increasing the number of culverts, installing 'splashpads' at culvert outlets, or realigning the culvert to discharge to land
			Condition and evidence of management of roadside drains	N		Y	Are roadside drains being managed? Is it a 'hit and miss' clearance techniques (partial clearance of drain vegetation and/ or sediment), or 'strimming'?
			Evidence of existing features present within the drains to slow/ disperse flow	Y	Check dams; relief culverts; other	N	E.g. check dams, relief culverts. Absence of data implies no
			Inappropriate culvert/ outfall placement?	N		Y	e.g. directly feeding into a channel with no sediment catchpit, relief culverts installed too close to the watercourse - instead of discharging at the inlet of the culvert, merely discharge on the bank at the outlet, where the water flows directly into the watercourse anyway.
			Evidence of residual water management produce in-situ?	Y	Silt fencing; straw bales; other	N	E.g. sediments, silt-fencing, straw bales
			NFM/ restoration opportunities	N		Y	
	Watercourses	To be surveyed from upstream to downstream from the river bank, if access permits. New entry to be made if conditions change. Information collected at the local scale, expected to represent sub-catchment.	Top channel width and bank heights	N		N	Estimate of width from left bank top to right bank top, bank heights from bank top to channel bed
			Wetted channel width and depth	N		N	Based on winter flow conditions, assuming flow is present
			Watercourse type (according to UKFS)	Y	Main River; Large watercourse; Medium watercourse; Small watercourse; Very small watercourse; Ephemeral	N	Main River (as defined by NRW maps), Large watercourse (channel >2m), Medium watercourse (channel 1-2m), Small watercourse (channel <1m), Very small watercourse (channel <0.5m), Ephemeral (natural channel but only activated in high/ seasonal flows)
			Channel slope gradient	N		N	Measured along the bank top using a clinometer
			River type and planform	N		N	I.e. single thread alluvial/ bedrock, multi-thread/ anastomosed, braided. Straight, sinuous or meandering.
			Bed sediment type	N		N	Description of bed material and grain size estimate (i.e. silt, sand, gravels, cobbles)
			Bank composition and profile	N		N	Description of bank material and profile (linked with processes)
			Flow types/ hydraulic habitat	N		N	List flow biotopes present (i.e. rapid, riffle, run, glide, pool)
			In-channel vegetation	N		Y	List species present if found
			Riparian vegetation and condition (if present)	N		Y	Describe vegetation type and condition (i.e. likely to be wetted frequently, biodiversity value). Riparian zone might not be present if the channel banks are particularly high
			Geomorphic features and processes	N		Y	I.e evidence of bed/bank erosion (scour, undercutting, incision) or deposition (bars, siltation)? Perceived connectivity with riparian zone/ floodplain (if present)?
			Geomorphic and ecological pressures	N		Y	E.g. Physical modification (weirs/ barriers/ other in channel structures, embankments, evidence of channel straightening/ realignment, evidence of dredging), siltation, pollution, intensive riparian management
			NFM/ restoration opportunities	N		Y	Are there opportunities to slow the flow, make the riparian habitat wetter, and improve wetland habitats (for biodiversity, capture suspended sediments, reduce downstream flood risk)?
	Riparian Zone	To be surveyed alongside the watercourse.	Distance between bank top and forestry management area	N		N	Estimate of distance from managed forests to channel bank top, based on vegetation type. Note if it is consistent across study area or variable.
			Size of riparian zone	Y	Absent; <1m; 1-3m; >3m	N	Limited (<1m), Average (1-3m), Extensive (>3m) FROM WATERS EDGE. Riparian zone based on vegetation communities, landforms (i.e. bank height and steepness) and any physical modification (i.e. tracks)
			Vegetation types present	N		Y	Description of key vegetation types present on the bank top and stretching back from the channel edge.
			Condition of riparian zone	Y	Good; Poor; Other"	N	Good/ poor - to be determined from ecological assessment. "Other to be used if more desciption is needed
			NFM/ restoration opportunities	N		Y	I.e. does the buffer zone needs to be expanded to limit forestry practices in the riparian zone? Can the condition of the riparian zone be improved?
	Forest Drains	To be surveyed on a 'spot check' basis within each sub-catchment that features a priority area.	Geometry and hydraulic habitat	N		Y	I.e. Channel width and depth, flow biotopes (or dry)
			Evidence of existing NFM	N		Y	I.e. has the drain been blocked and prevented from freely discharging into a more natural watercourse, is it effective? Has the forest drain been deflected to a J-drain or the adjacent hillslope where water can spread out and infiltrate.
			NFM/ restoration opportunities	N		Y	

Appendix B. Simplified inventory list

Proposed inventory and methodology for site/reach/area information

Sub-catchment	Feature type	*Frequency of survey/ collection notes*	Characteristic	Drop down value - Y/ N	Things to include in drop-down box	Larger text box - Y/N	*Examples/ more information*
Sub-catchment 01, 02, 03 etc	**Forest Roads**	*Spot check. To be surveyed from the car or on foot on route to and from sub-catchment headwaters. New entry to be made if conditions change.*	Road surface/ condition/ presence of vegetation	N		Y	*Describe the road surface and physical character, include whether any vegetation is present*
			Condition and evidence of management of roadside drains	N		Y	*Are roadside drains being managed? Is it a 'hit and miss' clearance techniques (partial clearance of drain vegetation and/ or sediment), or 'strimming'? Any check dams/relief culverts present?*
			Evidence of residual water management measures in-situ?	Y	Silt fencing; straw bales; other	N	*E.g. silt-fencing, straw bales*
			NFM/ restoration opportunities	N		Y	*Are there opportunities to slow the flow, divert to local land surface (for multiple benefits, e.g. capture suspended sediments, reduce downstream flood risk)?*
	Watercourses	*To be surveyed from upstream to downstream from the river bank, if access permits. New entry to be made if conditions change. Information collected at the local scale, expected to represent sub-catchment areas.*	Channel dimensions: - Top channel width and bank heights - Wetted width and depth	N		N	*Estimate of width from left bank top to right bank top, bank heights from bank top to channel bed* *Based on winter flow conditions, assuming flow is present* *Measurements can be used to help inform watercourse type* *Main River (as defined by NRW maps), Large watercourse (channel >2m), Medium watercourse (channel 1-2m), Small watercourse (channel <1m), Very small watercourse (channel <0.5m), Ephemeral (natural channel but only activated in high/ seasonal flows)*
			Channel slope gradient	N		N	*Measured along the bank top using a clinometer (ensure units of measurements are stated (e.g. degrees, %, m/m), typically over a 5m-20m reach length dependant on channel characteristics)*
			River type and planform	N		N	*i.e. single thread alluvial/ bedrock, multi-thread/ anastomosed, braided. Straight, sinuous or meandering.*
			Bed and bank composition/profile	N		N	*Description of bank material and profile (linked with processes)* *Description of bed material and grain size estimate (i.e. silt, sand, gravels, cobbles, boulders)*
			In-channel vegetation	N		Y	*List species present if found*
			Geomorphic features, flow types and processes	N		Y	*I.e evidence of bed/bank erosion (scour, undercutting, incision) or deposition (bars, siltation)? Perceived connectivity with riparian zone/ floodplain (if present)?* *List flow biotopes present (i.e. rapid, riffle, run, glide, pool)*
			Geomorphic and ecological pressures	N		Y	*E.g. Physical modification (weirs/ barriers/ other in channel structures, embankments, evidence of channel straightening/ realignment, evidence of dredging), siltation, pollution, intensive riparian management*
			NFM/ restoration opportunities	N		Y	*Are there opportunities to slow the flow, reconnect with the local floodplain, make the riparian habitat wetter, and improve wetland habitats (for biodiversity, capture suspended sediments, reduce downstream flood risk)?*
	Riparian Zone	*To be surveyed alongside the watercourse.*	Distance between bank top and forestry management area	N		N	*Estimate of distance from managed forests to channel bank top, based on vegetation type. Note if it is consistent across study area or variable.*
			Size of riparian zone	Y	Absent; <1m; 1-3m; >3m	N	*Limited (<1m), Average (1-3m), Extensive (>3m), measured from waters edge. Riparian zone based on vegetation communities, landforms (i.e. bank height and steepness) and any physical modification (i.e. tracks)*
			Vegetation types present	N		Y	*Description of key vegetation types present on the bank top and stretching back from the channel edge.*
			Condition of riparian zone	Y	Good; Poor; Other*	N	*Good/ poor - to be determined from ecological assessment. *Other to be used if more desciption is needed*
			NFM/ restoration opportunities	N		Y	*Should the buffer zone be expanded to limit forestry practices in the riparian zone? Can the condition of the riparian zone be improved?*
	Forest Drains	*To be surveyed on a 'spot check' basis within each sub-catchment that features a priority area.*	Geometry and hydraulic habitat	N		Y	*i.e. Channel width and depth, flow biotopes (or dry)*
			Evidence of existing NFM (artificially implemented)	N		Y	*i.e. has the drain been blocked and prevented from freely discharging into a more natural watercourse, is it effective? Has the forest drain been deflected to a J-drain or the adjacent hillslope where water can spread out and infiltrate.*
			NFM/ restoration opportunities	N		Y	*Are there opportunities to slow the flow, divert/reconnect with the local floodplain or local land surface (for multiple benefits, e.g. capture suspended sediments, reduce downstream flood risk)?*
	Open Ground and Overland Flow Pathways	*Box to be filled in on a 'spot check' basis within each sub-catchment that features open ground or an area with a natural overland flow pathway.*	Open ground and overland flow pathways	N		Y	*Are there any open ground areas? What is the dominant vegetation type? Is there any evidence of erosion? Are there any gullies? How does water travel through these areas i.e. does water follow natural topographic contours?*

Appendix C. Available data

The data provided by Natural Resources Wales is listed in Table 0-1

Table 0-1: Supplied data

Supplied data	Author(s)
Historic LiDAR Archive	Welsh Government and Natural Resources Wales (DataMapWales)
LiDAR Composite Dataset	Welsh Government and Natural Resources Wales (DataMapWales)
OS Base Data	OS Data Hub
Landmark/ OS Historic Mapping	National Library Scotland
Areas benefiting from Flood Defences	Welsh Government and Natural Resources Wales (DataMapWales)
Flood Defences with standardised attributes	Welsh Government and Natural Resources Wales (DataMapWales)
Geology (Solid and Superficial)	British Geological Society
Soils (e.g. NATMAP vector)	British Geological Society
Detailed River Network	Welsh Government and Natural Resources Wales (DataMapWales)
Flood Risk – Main Rivers	Welsh Government and Natural Resources Wales (DataMapWales)
Hydrometry & Telemetry Data	Welsh Government and Natural Resources Wales (DataMapWales)
Aberhirnant and Llangower approved Forest Resource Plan	Siviculture
Low risk Impoundment Position Statement	NRW
Forest Restock Coupes	NRW
NRW Forest Legal Boundaries	NRW
NRW Forest Roads	NRW
NRW Forestry Priority Catchments 2016	NRW
Water Watch Wales	Water Watch Wales (naturalresourceswales.gov.uk)
Welsh Peatland Data Portal, including Peatland of Wales Thickness	NRW
Project Study Areas	NRW
Fisheries Habitat Restoration Plan: Welsh Wye Catchment Report	NRW
Forestry Core Asset Layer (Roads, Bridges / Major Culverts)	NRW
River levels, rainfall and sea levels	NRW
Rainfall Data	NRW
NRW Forestry Blocks	NRW
NRW Forest Bridges	NRW
Flood Map for Planning TAN15 Defended Zones	Welsh Government and Natural Resources Wales (DataMapWales)
National Flood Risk Map	Welsh Government and Natural Resources Wales (DataMapWales)
National Flood Hazard Map	Welsh Government and Natural Resources Wales (DataMapWales)
Environment (Wales) Act Section 7 Terrestrial Habitats of Principle Importance	Welsh Government and Natural Resources Wales (DataMapWales)
Habitat Networks	Welsh Government and Natural Resources Wales (DataMapWales)

Supplied data	Author(s)
National Parks	Welsh Government and Natural Resources Wales (DataMapWales)
Sites of Special Scientific Interest	Welsh Government and Natural Resources Wales (DataMapWales)
Special Areas of Conservation	Welsh Government and Natural Resources Wales (DataMapWales)
Dee Water Protection Zone	Welsh Government and Natural Resources Wales (DataMapWales)
Ramsar Wetlands of international importance	Welsh Government and Natural Resources Wales (DataMapWales)
Special Protection Areas	Welsh Government and Natural Resources Wales (DataMapWales)
Open Access - Open Country	Welsh Government and Natural Resources Wales (DataMapWales)
20 years of aerial photography to help create a Drainage Map	NRW
Aberhirnant.zip	NRW
ATI-26082a PART A	NRW
Third Party mines and quarries GRA	NRW
AberhirnantRiparian	NRW
Approved Management Coupes shapefile	NRW
Forest Management and Felling Strategy	NRW
Forest Type and Restocking	NRW
Landcover Map 2018	NRW
Local Record Centre records	NRW
Forest Compartments	NRW
Forest Thinning Coupes	NRW
Future Restock Coupes for Aberhirnant	NRW
NRW Woodland sub-compartment data	Welsh Government and Natural Resources Wales (DataMapWales)
Ordnance Survey Basemaps, (3rd Party Data).	NRW
British Geological Survey (BGS): 50k Onshore Geology, (3rd Party Data).	NRW
UK Centre for Ecology and Hydrology (UK CEH): Landcover Map, 1990, (3rd Party Data).	NRW
UK Centre for Ecology and Hydrology (UKCEH): Land Cover Map 2000 and 2007, (3rd Party Data).	NRW
UK Centre for Ecology and Hydrology (UKCEH): Land Cover Map 2015, (3rd Party Data).	NRW
UK Centre for Ecology and Hydrology (UKCEH): Landcover Map, 2018, (3rd Party Data).	NRW
Landcover Map 2020.	NRW
Landcover Map 1990.lyr	NRW
Landcover Map 2018.lyr	NRW
Permanat Open Ground Aberhirnant	NRW
Aberhirnant Minor Culvert	NRW
Forest Resource Plan Approved Layers for Aberhirnant	

Appendix D. Glossary

Buffer area	An area of land that protects the watercourse or heritage feature from activities on the adjacent land, such as by intercepting polluted run-of. The buffer area will usually include the riparian zone and may extend into adjacent land.
Major culvert	A culvert that has a diameter greater than 1500m (1.5m) and located along named watercourses where designated forestry tracks cross.
Planform	A river's special configuration in terms of path, sinuosity, number of channels and their width, and the assemblage of in-channel geomorphic units (Nardini *et al.,* 2023).
Riparian	Relating to, or situated adjacent to, a watercourse or water body.
Run flow biotope	Flow that is deep with fast water and little to no turbulence.