GEOMORPHOLOGICAL ASSESSMENT

TO INFORM THE CUMULATIVE IMPACT OF THE GALEDFFRWD HYDRO ELECTRIC POWER SCHEME ON THE AFON GALEDFFWRD, BETHESDA, NORTH WALES

September 2018

HYDRO-MORPH
Water & Geomorphology Services

Revision	Description	Issued by	Date
00	Draft for comment	J Moon	10/09/2018
01	Final	J Moon	10/09/2018

Table of Contents

1. Introduction

1.1 BACKGROUND

Proposals have been put forward by a local community group and landowner (known collectively as Coetir Mynydd[1]) to generate hydro-power from a site along the Afon Galedffrwd, near Bethesda in North Wales. The site is located to the east of Mynydd Llandygai (grid ref: SH 60625 65514), along the Afon Galedffrwd which is a tributary of the Afon Ogwen, which flows to the north to enter the sea east of Bangor through the Bangor Flats. The proposed hydro site is approximately 2.7km upstream of the confluence with the Afon Ogwen.

The proposal is to reinstate a former HEP scheme which once existed at the site through the installation of a new hydro-power turbine and associated infrastructure. It is the intention the scheme will generate 232kW which will be used to supply the local community in Mynydd Llandygai.

Prior to development at the site, Ellergreen Hydro Ltd, which is leading the technical design and application for the community group, must obtain the relevant consents for the work from Natural Resources Wales (NRW) and ensure the scheme is compliant with the requirements of the Water Framework Directive (WFD).

The European WFD (Directive 2000/60/EC), implemented in England and Wales by the Water Environment (WFD) Regulations (SI 3242/2003); requires all natural water bodies to meet Good Ecological Status (GES) and all Artificial or Heavily Modified Water Bodies (A/HMWB) to meet Good Ecological Potential (GEP). Natural Resources Wales, as the competent authorities in Wales, is responsible for delivery of the WFD through the Regulations. The WFD needs to be taken into account in the planning of all new activities in the water environment.

Ellergreen Hydro Ltd carried out a WFD Assessment for the proposed HEP scheme in June 2017, which was subsequently updated to include a cumulative impact assessment in May 2018. However, it is understood NRW had concerns the assessment did not adequately quantify the impact of the proposed scheme taking into account existing pressures on the geomorphology of the Afon Galedffwrd. They have therefore requested a full quantitative Cumulative Impact Assessment is undertaken. In view of the above, Ellergreen Hydro Ltd have commissioned Hydro-Morph Ltd to carry out a cumulative impact assessment of the proposed scheme on the Afon Galedffwrd.

1.2 AIMS AND OBJECTIVES

The main objective of this work is to develop an understanding of the potential cumulative impacts of the scheme by carrying out a geomorphological assessment of the Afon Galedffwrd water body. The outputs of this report will be used to update the existing WFD assessment (outside the scope of this commission) to ensure the scheme does not lead to any adverse effect on the water body; cause a potential deterioration in status or prevent any actions required to raise the status of the water body from being implemented in the future.

The specific aims are:

- To undertake a review of existing data and a site visit to develop a baseline understanding of the Afon Galedffwrd geomorphology to identify any existing geomorphic pressures along the water body;

[1] Community Woodland Group

- To assess the impact of the proposed scheme, particularly in terms of sediment transfer processes and taking into account existing pressures along the Afon Galedffwrd.
- To assess the impact of the new modifications associated with the HEP scheme, in particular in relation to:
  - headward erosion and potential impact on existing structures (i.e. culvert and bridge) and adjacent land, and
  - sedimentation issues particularly within the new impoundment.
- To provide, if required, appropriate recommendations for mitigation in order to achieve WFD compliance.

1.3 METHOD

A desk assessment has been undertaken and the following data sources have been reviewed:

- Ellergreen Hydro Ltd Reports:
  - Galedffrwd Hydro Water Framework Directive Assessment, May 2018.
  - Galedffrwd Hydro Design and Access Statement. March 2017.
  - Galedffrwd Hydro Method Statement. March 2017.
  - Galedffrwd Hydro Pipeline Design Detail for low impact. May 2017.
- Flow data from the Felin Fawr Dam gauge (May 2006-May 2007)
- Historic Ordnance Survey Mapping (source www.old-maps.co.uk)
- Western Wales River Basin Management Plan (RBMP) 2015 – 2021. Including waterbody descriptors for the Ogwen – lower (GB110065058520) Water Watch Wales[2]

A 3km long walk over survey of the Afon Galedffwrd was undertaken on the 3rd September 2018, extending from the confluence with the Afon Ogwen to upstream of the proposed site of the HEP intake at Mynydd Llandegar. In addition, two spot checks were taken along adjoining tributaries further upstream. Features were recorded using geo-referenced photographs (see Appendix A). The weather conditions were initially cloudy and drizzly but improved to dry and bright. The survey followed a period of generally dry weather so the water depth on the day of the survey was at the normal to lower end of the depth range[3].

Sediment grain size samples were also taken at two locations along the stream to provide some simple quantified information on bed surface grain size and channel dimensions along the reach. One sample was taken just downstream of the Coed Y Parc reservoir (at the downstream end of the proposed HEP scheme) and another was taken upstream of the Pen y Bont historic dam (just upstream of the proposed water intake to the HEP scheme), see figure 2.1 The procedure (a 'Wolman Pebble Count', see Appendix B) recorded the size of 100 sediment particles randomly selected in a transect across the full river width.

1.4 REPORT STRUCTURE

This report is divided into four sections:

- Section 1: Introduction, background and method
- Section 2: Geomorphological assessment
- Section 3: Impact assessment
- Section 4: Conclusions and recommendations

[2] http://waterwatchwales.naturalresourceswales.gov.uk/cy/

[3] This assumption was checked against available river gauge data from a local site (Nant Peris) which recorded levels to be in the normal to lower range.

2 Geomorphological Assessment

2.1 CATCHMENT OVERVIEW (TOPOGRAPHY, GEOLOGY AND LAND USE)

The Catchment of the Afon Galedffrwd is small, approximately 4km^2 and is located on the edge of the Snowdonia National Park. The head of the catchment rises at an elevation of around 630m AOD from the northern flank of Elidir Fawr and flows in a north easterly direction to join the Afon Ogwen near Bethesda, at 120m AOD. There are a number of spring and reservoir fed tributaries at the head of the catchment which feed into the Afon Galedffrwd water body, including the Afon Marchlyn-Mawr which is fed from the Marchlyn Mawr Reservoir (located within the National Park), all the other tributaries are un-named. The Marchlyn Bach Reservoir (also located within Snowdonia National Park) feeds another (un-named) tributary at an elevation of approx. 480m AOD. These tributaries flow towards the north-west before becoming a single-thread channel just upstream of Mynydd Llandegai at approximately 270m AOD, which is where the watercourse becomes named Afon Galedffrwd. The proposed HEP intake is located approximately 2.7km upstream from its confluence with the Afon Ogwen, see figure 2.1.

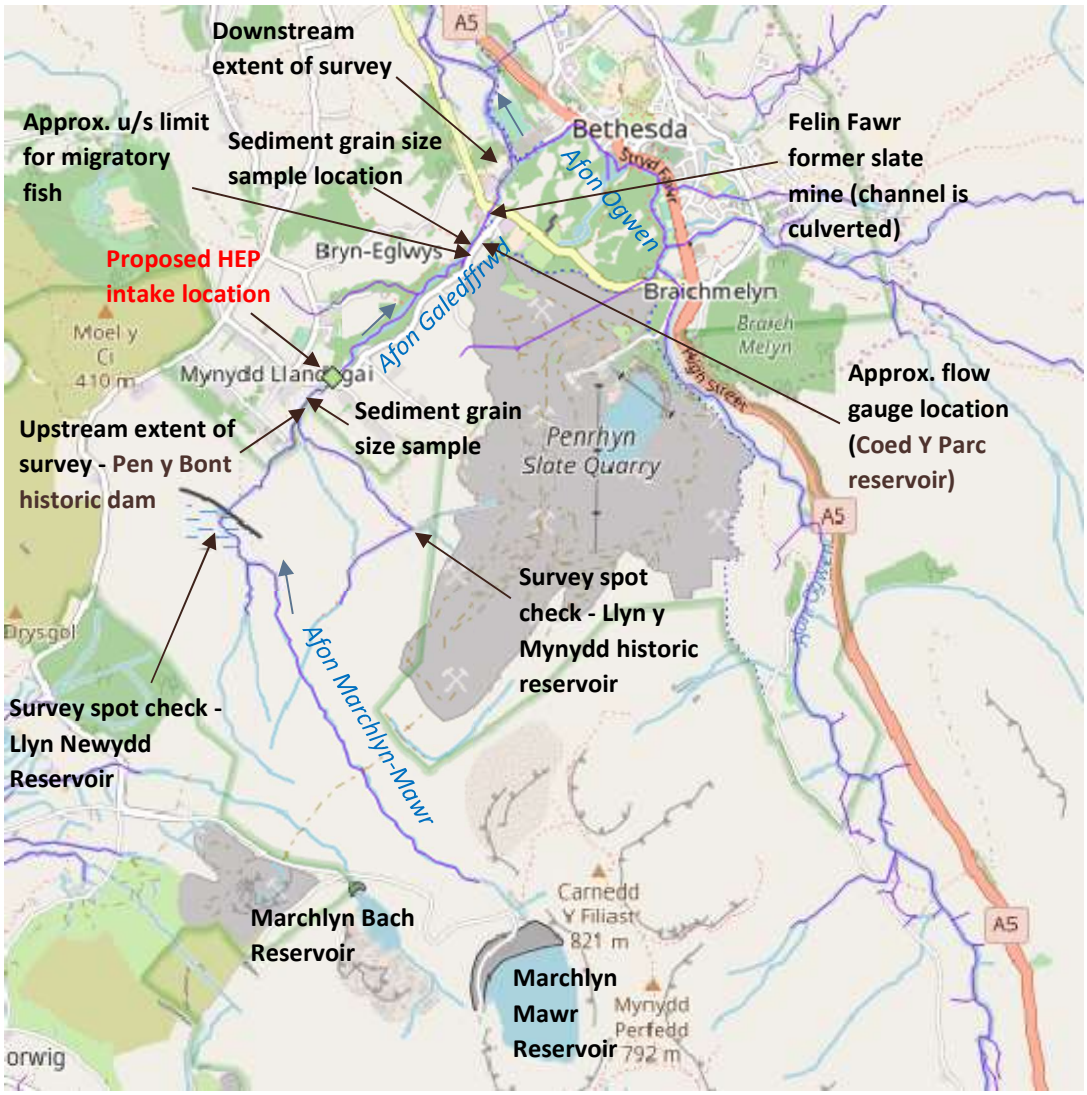


Figure 2.1: Catchment location plan.

The land-use of the Galedffrwd catchment is predominantly rural, dominated by heathland and moorland at the head of the catchment, and dense woodland and rough grazing further downstream. There are several small villages and hamlets such as Mynydd Llandegai and Bryn Eglwys. Mining activity has been undertaken in the area and the large active Penrhyn Slate Quarry is located just to the east of the watercourse, see figure 2.1. There are also several dams along some of the upstream tributaries of the watercourse which are associated with past mining operations in the area (see Appendix C for further detail).

The bedrock geology of the catchment, which is exposed in places along the Afon Galedffrwd channel is characterised by sedimentary sandstone, mudstone and siltstone associated with the Llanberis Slates Formation. There is a distinct change at the top of the catchment, which opens out into a heath and moorland landscape and is underlain by igneous (volcanic) bedrock consisting of tuff and felsic rocks associated with the Padern Tuff Formation[4].

Due to the narrow confining valley and floodplain of the Afon Galedffrwd there are no significant superficial deposits along the valley until it joins the confluence of the Afon Ogwen, where there is a narrow floodplain composed of alluvium (clay, silt, sand and gravel). At the upper end of the catchment superficial glacial till deposits are found.

The soils in the catchment reflect the underlying geology of the area and are typically characterised as slowly permeable seasonally wet loamy and clayey soils becoming more free draining further towards the lower end of the catchment. The upper catchment is characterised by wet and very acid upland peaty soils.

The groundwater vulnerability map published by the British Geological Survey shows the catchment of the Galedffrwd is underlain by a secondary aquifer. The upper catchment is generally assessed as being at low to medium risk in terms of groundwater vulnerability but increases to high vulnerability where the Galedffrwd flows into the Afon Ogwen floodplain.

The stream is not gauged by the Environment Agency; however, some hydrology data has been obtained from the Felin Fawr Dam by Ellergreen Hydro to determine flow characteristics for the catchment. The gauge records flow along the Afon Galedffrwd at the Coed Y Parc dam, upstream of the powerhouse, see figure 2.1. According to this data the catchment receives approximately 2000mm of rainfall annually (classified as high rainfall). The gauged data provides an annual flow record extending from May 2005 to May 2006, recording a mean annual flow of 0.43m³/s and a maximum flow of 8.94m³/s, see figure 2.2.

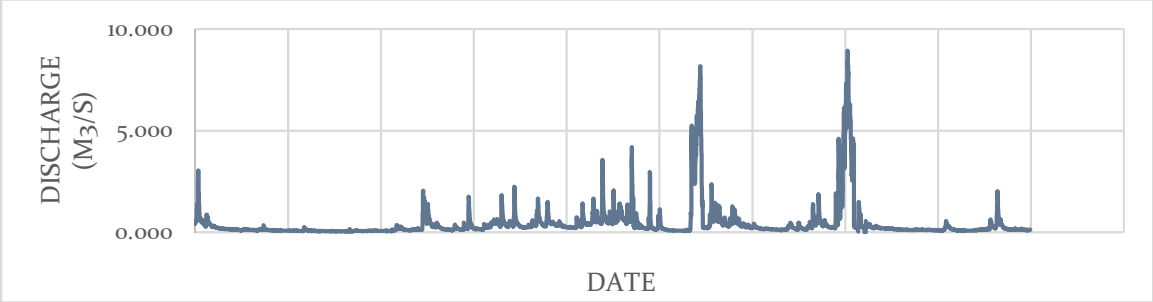


Figure 2.2: Daily flow records taken at Coed Y Parc dam, upstream of the powerhouse on the Afon Galedffrwd: May 2005 – May 2006.

[4] Geological information was obtained from the British Geological Survey 'Geology of Britain' at http://mapapps.bgs.ac.uk/geologyofbritain/home.html.

2.2 WATER FRAMEWORK DIRECTIVE STATUS

The WFD aims to protect and improve the water environment by setting objectives to meet 'Good Status' for surface and groundwater bodies in terms of biological, physical and chemical elements, as described in River Basin Management Plans (RBMPs). The Western Wales RBMP includes the study area of the Afon Galedffrwd. The current period of river basin planning under WFD runs from 2015-2021, with final targets to be met by 2027. The proposed HEP site is located along the Afon Galedffrwd, which is not classified directly under the WFD, however, it is located within the river catchment of the 'Ogwen – lower' WFD river water body, ID GB110065058520. This water body has in the latest 2015 RBMP cycle2 update been reclassified as being at good ecological and chemical status[5] (see Table 2.1).

Water body details			**WFD status (2015)**
Water Body Name	Ogwen - lower		Good Ecological Status
Catchment	Llyn and Eryri	29.03 km^2	Good Chemical Status
WFD ID	GB110065058520	Mid, Small, Siliceous	

Table 2.1 – 2015 WFD status for Afon Galedffrwd

Unclassified water bodies such as the Afon Galedwffrd should be assessed against the classification given for the closest adjacent water body (in this case the Ogwen – lower). Observations from the site visit, however, indicate this waterbody has been extensively modified due to past industrial activity within the catchment. Therefore, it is conceivable that if it were given its own classification, it would be classified differently to the 'Ogwen-lower' and possibly classified as a heavily modified water body (HMWB). However, given the existing 'good' status of the 'Ogwen-lower' any proposals for the Galedffrwd will need to be assessed against this status, as this will take into account any existing pressures and modifications along the water body.

2.3 FISH PASSAGE

The WFD classification does not specifically cite data for fish, however, a report produced by NRW provides information on the status of salmon and sea trout populations in the Ogwen catchment. It reports migratory salmon have access to most of the main Afon Ogwen, however a waterfall at the outlet of Llyn Ogwen is a natural barrier which prevents access to the lake and upper tributaries. This barrier is however upstream of the Afon Galedffrwd confluence, so it is reasonable to assume salmon and sea trout can find their way into the Afon Galedffrwd water body.

This assumption is supported by evidence collated during the initial feasibility investigations for the project. It is understood the Environment Agency carried out river survey in May 2010 and confirmed the downstream end of the river is used by migratory fish, with the upstream limit being the weir just upstream of the culvert through the Felin Fawr site, adjacent to the proposed outfall[6] (see figure 2.1 and photo A7 in appendix A).

2.4 BASELINE GEOMORPHOLOGY (FEATURES AND PROCESSES)

Geomorphological characteristics of the Afon Galedffrwd water body are summarised below.

[5] Water Watch Wales http://waterwatchwales.naturalresourceswales.gov.uk/en/ data download 'Wales Water Body Objectives and measures update 2015.xlsx'

[6] Dulas Hydro Ltd. Galedffrwd Hydro Pre-feasibility Report. April 2010. H2769-REP-001(B)

2.4.1 Channel gradient

The Afon Galedffrwd channel has a steep gradient, average 0.065 (based on analysis of LiDAR topographic data), which is characteristic of a boulder stream typology (figure 2.3). The channel is typically single thread and straight confined by steep valley sides and a narrow undeveloped floodplain. In places the channel is even steeper (almost vertical), due to natural cascades (boulder weirs) and manmade cascades formed behind weirs and dams.

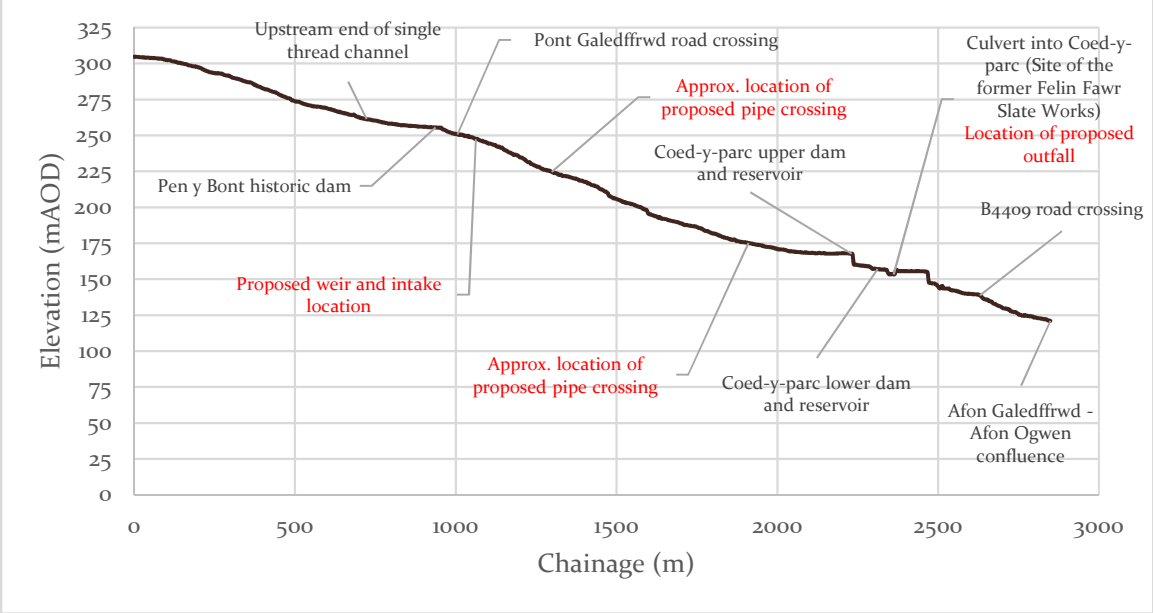


Figure 2.3: Afon Galedffrwd long-section (taken from LiDAR topographic data) *(red text identifies features associated with the proposed HEP scheme).*

2.4.2 Channel banks

The channel banks are characterised by bedrock exposures and vegetated (moss covered) boulder and drift deposits (see photos in appendix A). The banks are vegetated with mature deciduous trees which grow along much of the valley, shading the channel. Further upstream where the channel opens out into moorland and the banks are typically shallow, cutting through peat deposits, with grass and heather vegetation cover.

2.4.3 Sediment

Grain size data was obtained at two locations along the Afon Galedffrwd, see Table 2.2.

Location	NGR mm	D_{50} (mm)	D_{84} (mm)	Site description
Site 1: Downstream of Coed-y-parc dam and lower reservoir	SH 61460 66256	80	184	Boulder bar located within a bedrock confined narrow valley. Dense woodland. No floodplain.
Site 2: Upstream of intake site and just u/s of Pen y Bont historic dam	SH 60491 65408	58	128	Gravel bed and bar. Less confined floodplain. Narrow channel within typically straight planform

Table 2.2: Grain size data for the Afon Galedffrwd

Channel bedload is typically very coarse, ranging from fine gravel (4-5.6mm) to very large boulders (=>362mm diameter). The median grain size (D_{50}) is characteristic of very coarse gravel to small cobble and the D_{84} is defined as large cobbles.

The bedload sediment of the Afon Galedffrwd appears to be locally derived from erosion of the underlying bedrock strata and banks. Bedrock is also exposed in places along the channel.

The presence of finer gravel sized sediment appears to be limited, but where it does occur it appears to be derived from erosion further upstream in the catchment. This finer bed substrate was only observed in locations where stream energy was low, such as where the channel has widened out and deposited gravel bars adjacent to the main low flow channel. In addition, the finer gravel substrate was observed to be armoured by an overlying coarse (and typically less mobile) cobble and boulder substrate.

It was observed, during the site visit, the downstream channel below the lower dam at Coed-y-parc had a slightly coarser bedload, possibly due to the slightly steeper channel gradient in this area than compared to upstream, see figure 2.3. This coarsening of the bed substrate is also identified in the grain size analysis (see Figure 2.4).

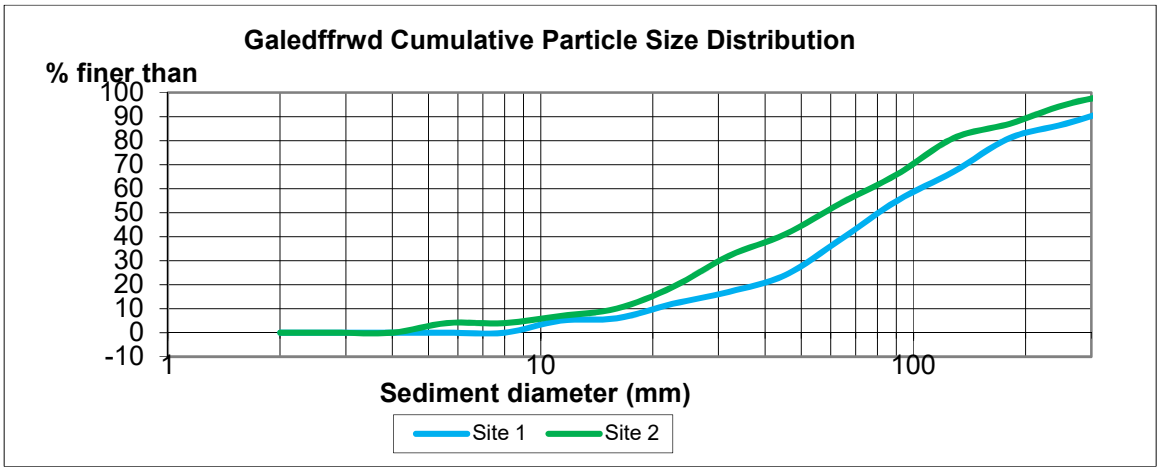


Figure 2.4: Particle size distribution measured at the two sites.

Channel turbidity was generally low and, it is assumed, given the available source material, suspended sediment load is a minor constituent of the total sediment load of the stream.

2.4.4 Sediment transport

Observational evidence gained during the site visit, combined with sediment transport calculations have been used to determine the potential for movement of the bed substrate along the Afon Galedffrwd. This information has been used to establish (1) if the existing bed substrate is able to be mobilised, and if so (2) how frequently and what flows are required to mobilise the substrate.

Sediment transport calculations have been undertaken using sediment grain-size data to establish a threshold velocity for sediment entrainment of the D_{50} and D_{84} grain size at the two sites sampled, using the Hjulstrum curve method. Channel dimensions measured at each of the two sites were then used to determine the critical entrainment discharge (Q_{crit}). These results provide an indicative estimate of sediment transport potential within the channel, see table 2.3.

Based on the D_{50} grain size

Sediment movement threshold to initiate transport (Hjulstrum method)				Sediment movement discharge Qcrit = VA	
Location	D50 (mm)	Min Velocity m/s	Max Velocity m/s	Bankfull flow area (m^2)	Average (m^3/s)
Afon Galedffrwd Site 1 (D/S)	80	0.9	3.8	5	12
Afon Galedffrwd Site 2 (U/S)	58	0.8	3	2	3.2

Based on the D_{84} grain size

Sediment movement threshold to initiate transport (Hjulstrum method)				Sediment movement discharge Qcrit = VA	
Location	D84 (mm)	Min Velocity m/s	Max Velocity m/s	Bankfull flow area (m^2)	Average (m^3/s)
Afon Galedffrwd Site 1 (D/S)	184	2.5	7	10	24
Afon Galedffrwd Site 2 (U/S)	128	1.8	6	2	12.6

Table 2.3: Indicative critical entrainment thresholds for sediment movement along the Afon Galedffrwd.

Analysis of an annual flow record (May 2005-May 2006) shows that the average Qcrit for the D_{50} recorded at site 2 (which is just upstream of the proposed HEP site) is exceeded during approximately 4 high flow events. This suggests there is potential for sediment transport of the D_{50} grain size (58mm or finer) recorded at site 2, which is upstream of the proposed HEP site. However, there is no movement predicted of the D_{84} grain size (128mm or larger) at site 2. In addition, the Qcrit estimate for the sediment sampled at site 1 (downstream of the lower dam at Coed-y-parc) for both the D_{50} and D_{84} sizes indicates there is unlikely to be any sediment movement along the channel.

Observational evidence of moss covered cobbles and boulders also points towards a largely immobile coarse bed substrate. In many places bedrock is also exposed along the channel bed and is being kept exposed by frequent high flows along the channel (i.e. has not been buried through sediment transport and deposition). The presence of finer gravel (sediment sized smaller than 58mm) appears to be limited and where it does appear, it is not easily entrained due to armouring by the coarse overlying bed substrate.

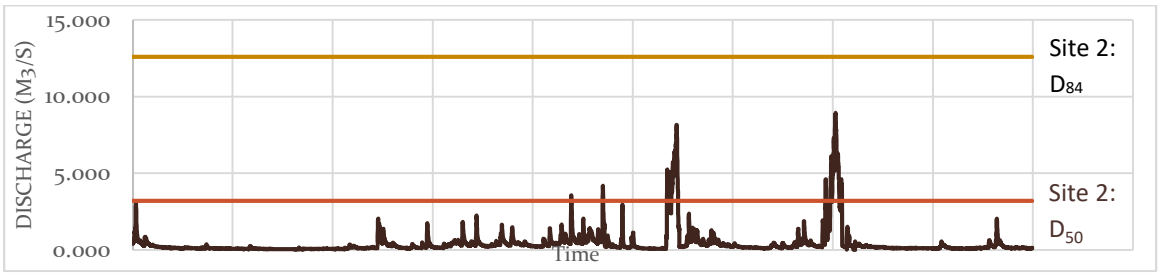


Figure 2.5: Daily flow maxima, Afon Galedffrwd May 2005 – May 2006.

3 Impact Assessment

3.1 PROPOSED HYDRO-ELECTRIC SCHEME

The proposal is to reinstate a former hydro site within the wooded valley of the Afon Galedffrwd downstream of Mynydd Llandegal. The proposed HEP infrastructure is designed to follow the footprint of the former HEP scheme where appropriate.

The works will include:

- A **small stone-faced concrete intake structure** across the watercourse, incorporating a trash screen (1mm apertures), and an adjacent buried stilling chamber. (Grid ref: 260625, 365514)
- A **new weir** to be located at a natural step (cascade) along the watercourse. This structure will incorporate an **informal pool type fish pass** to one side of the weir. The weir is to be backfilled with retained channel bed material. The weir will retain water to a level of 246.65m AOD.
- A 560mm diameter, **1250m long pipeline** running from the intake down to the turbine house on the west side of the watercourse. Some of the pipeline will be over ground, some overburdened and some buried.
- Two **new pipe bridge** crossings. These will be built at the site of a former crossing points and will retain some of the original historic bridge pillars. Some new works within the river will be required where the river has undermined the old bridge pillars, in these areas new pillars are to be constructed.
- A stone clad **turbine house** building enclosing the hydroelectric turbine, generator, control panel and metering. (Grid ref: 261473 366303)
- A 7m 600mm diameter **tailrace pipe with a screen** with 10mm spacing, which will discharge through an existing masonry **outfall** forming a cascade (waterfall) to return water to the beck at the rear of the powerhouse. This will prevent fish and other aquatic life from entering the pipe. (Grid ref: 324408 513861)

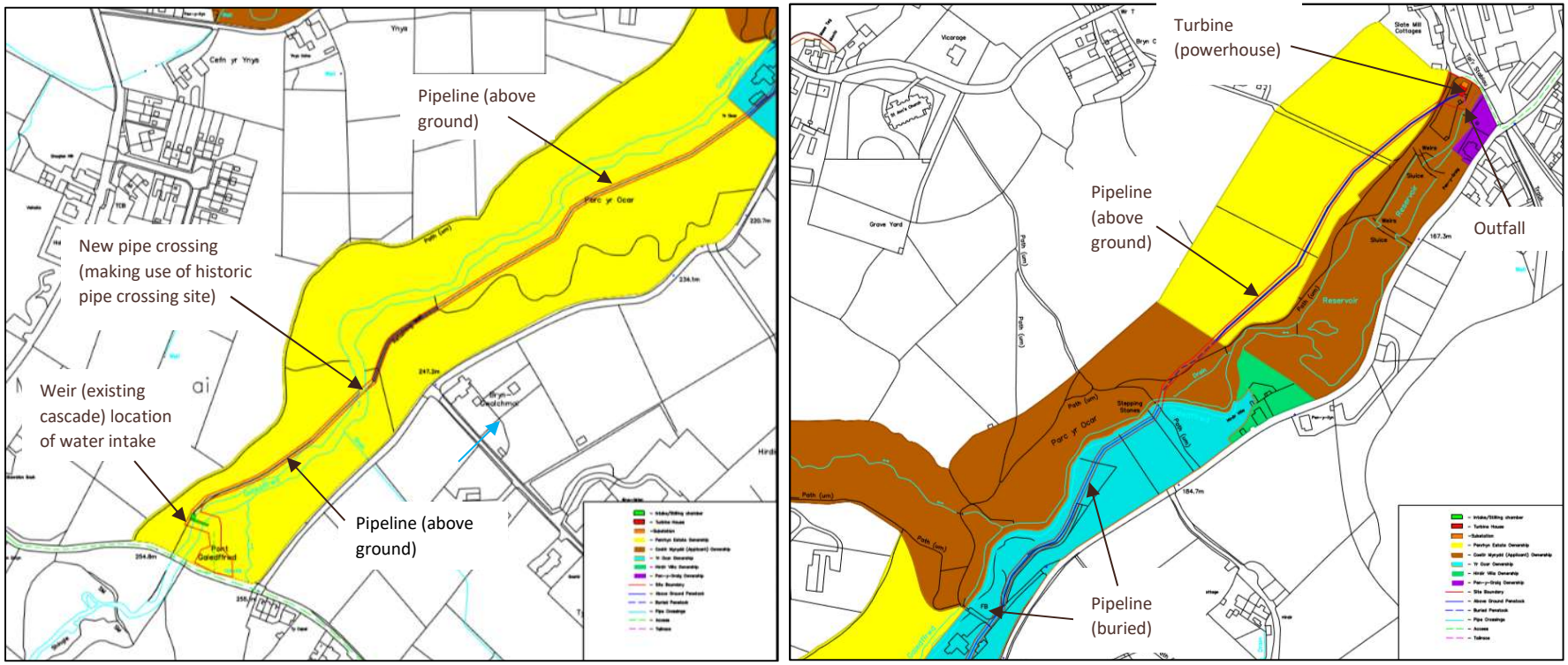


Figure 3.1: Plan showing the proposed HEP works along the Afon Galedffrwd.

3.2 CUMULATIVE IMPACT ASSESSMENT

An assessment has been undertaken to determine the cumulative impact of the proposed HEP scheme given our understanding of existing modifications along the watercourse. Particular regard has been given to sediment transport processes in order to assess if the new works are likely to compound any existing issues, potentially leading to a deterioration in terms of the classified WFD water body status.

3.2.1 Barriers to sediment transport

Historic Ordnance Survey maps[7] were reviewed prior to the walk-over survey to identify any historic modifications along the watercourse. This desk-based assessment was then added to from observations made during the site walkover and structures and features were recorded using georeferenced photographs. This work has identified over 15 man-made structures and modifications along the Afon Galedffrwd, see figure 3.2. A summary is provided in Table 3.1 with further detail given in Appendix C.

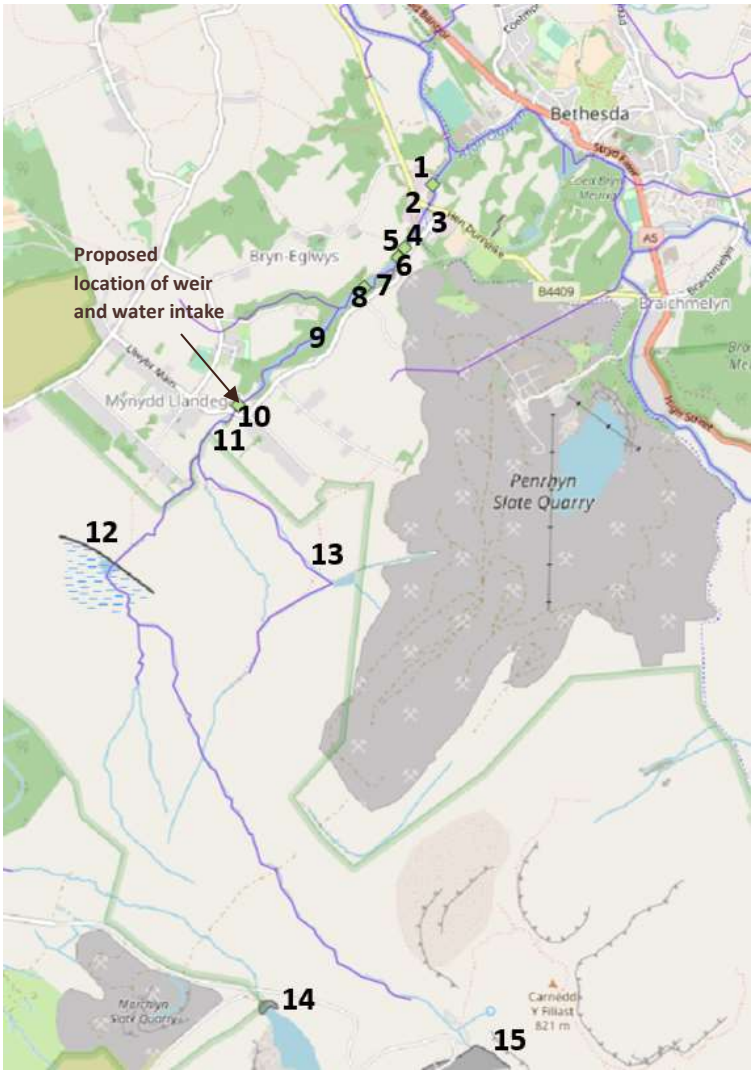


Figure 3.2: Location of existing modifications along the Afon Galedffrwd.

[7] Source: OS 25-inch mapping from 1892-1914 from http://maps.nls.uk/geo/explore

Modification	No. of features identified	How many are barriers to sediment transport
Dams and reservoirs	7 (4 – active sites and 3 historic)	All
Weirs	3	None – as the bed level upstream is level with the weir crest
Culverts	2	1
Bridge / stepping stones	3	Unknown but unlikely

Table 3.1: Summary of channel modifications identified along the Afon Galedffrwd.

Of all the structures observed none of the weirs are significant barriers to sediment transport due to having a weir crest at roughly the same level as the bed upstream, which will enable sediment, that is able to be mobilised, to be transported over the structure.

The culvert under the former Steel Works site was also not considered to be a significant barrier to sediment transport due to retaining a natural bed substrate.

The two culverts located approximately 60m upstream of the proposed intake (under the road bridge) are considered a restriction to sediment transport due to their narrow size across the channel. During the site visit it was observed woody debris had built up within both culverts slightly blocking them (see photo A18 in appendix A). It is likely high flows would wash accumulated woody material further downstream but, given the small size of the culverts, the same high flows are unlikely to transfer any significant amounts of sediment further downstream.

The modifications that appear to be having the most impact on geomorphic processes, in terms of sediment transport along the Afon Galedffrwd are the dams and reservoirs. There are seven dams in total; two at the very head of the catchment, Marchlyn Bach, which was a natural corrie but was enlarged to create further storage capacity. This reservoir is classified as a Drinking Water Protected Area[8] and is owned and managed by Welsh Water. The larger Marchlyn Mawr reservoir provides a supply of water to the Dinorwig Hydro-Electric Power Station.

There are also two historic dams in the upper catchment, the Lyn Owen-y-ddol dam and reservoir and which is part of the network of dams and leats formed in the 19th Century for Felin Fawr mill. The dam still retains some water but the weir outfall into the tributary that flows into Afon Galedffrwd has since been breached. There is also the Llyn Newydd dam, which has since been breached and only retains a small reservoir today.

These four (upper catchment) dams will capture sediment (particularly fines which will settle out of suspension), however, given the coarse bedload of the Afon Galedffrwd, which is what defines its geomorphic character (as a boulder stream), the impact of reduced fine sediment supply is unlikely to be having a significant impact on the overall geomorphic character of the water body.

There is a former historic dam (Pen y Bont) located approximately 65m upstream from Pont Galedffrwd bridge (which is a short distance upstream from the proposed HEP intake). The dam still exists but no longer retains a reservoir behind it, however, the gap in the dam through which water flows is very narrow. This

[8] Source: Water Watch Wales https://nrw.maps.arcgis.com/apps/webappviewer/index

structure, along with the culverts through the Pont Galedffrwd bridge, are both considered to be potential barriers to any significant bedload sediment transfer from the upstream reach.

Further downstream there are two more dams located directly along the Avon Galedffrwd watercourse. The lower dam is located approximately 30m upstream from the culvert of the former slate works. During the site visit it was observed the dam was not retaining any impounded flow behind it. However, the dam is a significant barrier across the full width of the water body, with flow maintained through a very narrow (1m wide) weir that cuts through the dam. It is therefore likely that during high flows, water will be impounded behind the structure and sediment transport, particularly bedload transport, will also be severely impeded.

Immediately upstream from the lower dam there is another second, much larger dam, which creates a waterfall some 10m in height. The weir impounds the Afon Galedffrwd for approximately 100m upstream, creating a narrow flooded valley. The bed substrate is notably different along this short stretch of channel with a greater degree of fine sediment deposition due to the impounded, slow flow conditions (see photo A10 in appendix A). There is also a much higher degree of channel turbidity within the impounded reach. In terms of impact, this modification is probably having the most significant impact on the waterbody in terms of reduced sediment transport and uncharacteristic bed substrate and riparian habitat quality and type.

3.2.2 Potential cumulative impact from the HEP proposals

Sediment transport calculations and observations from the geomorphological survey of the 3km reach indicate sediment transport is fairly limited along the Afon Galedffrwd. Much of the bed of the channel appears to be stable, confined either by bedrock or by large boulders that are unlikely to ever be mobilised. The proposed HEP works will however create another structure along the channel, and within a reach that is largely devoid of any significant modifications.

There are 15 identified modifications already located either within the catchment or located directly along the water body. Of these, eight are likely to be barriers to sediment transfer, though only four are considered to be barriers to bedload sediment transport.

Two of these are located a short distance upstream from the proposed HEP weir and intake (upstream of the Pont Galedffrwd road bridge). Bedload calculations indicate the D_{50} grain size can be mobilised in this area, however, it is likely these two existing restrictions (i.e. the two bridge culverts and the historic dam) will limit how much sediment is able to be transferred into the reach downstream of the road bridge and upstream of the new weir).

Further downstream at Coed Y Parc, there are two dams located directly on the Afon Galedffrwd, both are major barriers to sediment transport, particular the larger upper dam and it is unlikely any bedload material is delivered to downstream reaches past either of these two significant channel modifications.

The proposed design of the HEP scheme, (in particular the weir, which it is understood will take on a form similar to other weirs located along the channel), plus the bed behind being reinstated to crest level, will ensure the structure is not a significant barrier to sediment transport.

Given the existing structures along the water body, **the proposed works are unlikely to compound any existing issues in terms of sediment transport and the potential cumulative impact on the Afon Galedffrwd is therefore considered to be low/negligible** within the overall context of the existing modified geomorphic character of the water body.

3.3 IMPACT ASSESSMENT – NEW MODIFICATIONS

In addition to the cumulative impact, as assessed in the previous section, the proposed HEP scheme has the potential to cause both direct and indirect impacts on the water body, which also need to be assessed to determine if there are any adverse effects on a water body or the potential to cause a deterioration in status. The following modifications have therefore been assessed in more detail:

- Weir and fish pass
- Pipe bridge crossing
- Reinstatement of flow through the outfall
- Abstraction / reduced flow within the flow depleted reach

The impact on each modification is discussed below.

3.2.1 Impact of a new weir and fish pass

The proposal is to construct a new weir and fish pass immediately downstream of an existing boulder cascade approximately 60m downstream of a road bridge and culvert. The weir is to be located at the base of an existing boulder cascade which has a 1m (approx.) drop across it[9]. The crest level of the new weir is expected to create a 1.25m water level difference across the structure. The area immediately behind the weir is to be backfilled for approximately 1m upstream with retained channel bed substrate.

The structure, which is to be a fixed crest weir with notches cut into it to maintain low flows, will create a new physical barrier along the channel, which could have the following implications:

- Potential reduction in sediment transport.
- Potential impact upstream, such as on existing structures and adjacent land

Potential reduction in sediment transport

The proposed location of the new weir and fish pass is along a relatively unmodified stretch of river in comparison to downstream reaches, with a steep, step-pool boulder stream morphology. As described in section 2.4.4 the potential for sediment transport along the Afon Galedffrwd is fairly limited and only the D_{50} (58mm grain size or less) is likely to be readily transported and only then during infrequent high flow events. In addition, the upstream culvert and Pen y Bont historic dam both restrict sediment supply from upstream to downstream reaches. However, the weir does have the potential to effect sediment transfer processes by slowing the flow upstream and causing sediment to be deposited behind the weir and not transferred further downstream.

The current proposal (as of April 2018) is to backfill the area immediately behind the weir with retained gravel (i.e. the bed substrate from the footprint of where the weir is to be constructed) up to the level of the weir crest. By doing so, the bed profile will be maintained so sediment transfer processes would be unaffected (i.e. there will be no significant barrier).

There is a risk, however, especially given the potential reduced sediment supply available from upstream reaches, some of the reinstated bed substrate (especially any of the smaller size fraction) will be washed out during the first high flows following construction, leading to scour of the bed and potentially gradual headward erosion of the channel bed upstream, towards the road bridge.

[9] Based on personal communication and observation during the site visit. There is no topographic survey of the channel available.

The risk of headward erosion, however, is considered to be low for the following reasons:

- The shallow depth of the underlying geology is exposed at the surface in many places along the channel, which will protect the bed of the channel.
- Large boulders located within the channel will protect the bed.
- No evidence was obtained during the walkover survey of any headward erosion or significant bed scour along the channel suggesting the bed of the channel is fairly erosion resistant, even though it is a dynamic high energy flow environment.

A more real concern however is any loss of the reinstated bed substrate upstream could damage the weir itself (or lead to it being undermined, though this is unlikely given the reason stated above about bedrock). However, given there is no data to confirm the depth of bedrock and lack of any significant sediment supply delivered from upstream, it is recommended the reinstated bed behind the weir should make use of material larger than the D_{50} grain size (recorded for site 2) to reinstate the bed behind the weir up to the crest level, with the smaller size fraction used only as a top dressing. In addition, it is understood the design will look to minimise disturbance to any of the existing large boulders in this area which will also help to protect the upstream face of the structure.

Providing the bed substrate behind the weir can be maintained in this way, the impact of the weir itself on sediment transport processes, should be negligible. In addition, the design of the weir and reinstated bed behind it should help prevent any potential blockage from woody debris mobilised in the upstream reach[10]

Potential upstream impacts

There is no topographic survey available of the channel around the proposed intake and weir, so levels have been inferred from freely available LiDAR data. This data indicates the channel immediately below the bridge and culvert is at an approx. elevation of 250mAOD and the weir is to be constructed approximately 60m from the bridge. The proposed crest level of the weir is 246.65m AOD. Given the steepness of the channel gradient and (approximate) 3m bed elevation difference it is considered **very unlikely there will be any direct impact on the upstream bridge and culvert in terms of creating impounded conditions** which could lead to increased deposition within the culvert channels and increasing the risk of blockage. There is also consequently **unlikely to be any impact on the upstream channel and adjacent land-use**. Instead the impoundment is likely to be very localised in extent and only significantly effecting the existing boulder weir immediately upstream which will become submerged.

3.2.2 Pipe bridge crossings

Two pipe bridge crossings are proposed along the Afon Galedffrwd. Both bridges will span across the full bankfull width of the river. The design will make use of existing bridge pillars, where present. In most places the pillars are set back from the channel edge and therefore won't impact on it. However, in one location the proposal is to use an existing old pillar that has been undermined. It is not clear what has caused the pillar to be undermined (i.e. perhaps through scour of the channel bed). Therefore, **there is a risk the new structure could be undermined in a similar manner. It is recommended therefore, if feasible, the new pillar should be located further back from the channel edge to avoid the need for any work within the channel** and also to mitigate for any potential future scour around the structure.

[10] The two culverts under the road bridge were both observed, during the site visit on 3rd September 2018, to be partially blocked by woody material.

3.2.3 Reinstatement of flow through the outfall into the Afon Galedffrwd

There is the potential for erosion of the stream banks and bed immediately downstream of the exit from the outfall when the HEP scheme is in operation. It is understood however, an existing masonry outfall structure is to be used, which is located so water will cascade onto the bedrock channel beneath. Therefore, **the potential for erosion and scour of the channel or banks due to reinstatement of flow within the outfall is considered to be low.**

3.2.4 Abstraction of water from the stream creating a 'flow depleted' reach

A proportion of the flow from the Afon Galedffrwd will be routed into the intake and pipeline through to the turbine before rejoining the channel 1.3km downstream. This will reduce the available flow within the Afon Galedffrwd Stream channel over a similar distance (referred to here as the 'flow depleted' reach).

It is envisaged the turbine will draw a flow at a rate not exceeding 0.355m3/sec (which is the mean annual flow of the river). The Hands of Flow (HOF) has yet to be agreed but is likely to be allocated as the Q95. This is to be guaranteed through the construction of a rectangle notch built into the weir, to ensure the Q95 (or HOF) is maintained within the river before any flow enters the pipeline to the turbine. The abstraction ratio (also to be formally agreed) is likely to be based on a percentage of 70% take above the HOF, with 30% remaining within the reach in addition to the hands-off flow. This ratio is to be maintained by two open rectangular notches within the weir.

Low flow conditions are of fundamental importance to the ecological status of the watercourse and any change in the seasonal pattern of flows, brought about by the proposed abstraction could lead to irreversible changes to both the quality of the water and the stream ecology. For this reason, it is important the implications of reduced flow regime on the 1.3km 'flow depleted' reach is appropriately assessed.

Given the baseline understanding of the reach downstream of the intake and weir, with its steep, step-pool channel morphology which is confined within a narrow, steep valley, the natural channel topography and morphology will help to mitigate for most of the potential impacts caused by abstraction. The channel already has a very variable planform width, which can easily accommodate both low and high flows. In addition, HOF will ensure low seasonal flows will continue to be unaffected along with high flows, during which time the HEP scheme will not operate. Splash habitat (i.e. moss) is formed where flow cascades over boulders (or weirs) into pools and is important habitat along the reach. However, when the HEP scheme is in operation, **there is unlikely to be any significant detrimental impact on the seasonal flow regime and therefore it is not envisaged this habitat will be affected by the proposed operation of the schem**e.

4 Conclusions and Recommendations

The following issues have been identified in this assessment:

- potential loss of the reinstated bed substrate upstream, which could lead to damage to the weir itself or lead to it being undermined, and
- potential for the new pipe bridge pillar to be undermined if cited within the river.

To mitigate these potential negative impacts on the water body and to ensure WFD compliance, the following recommendations are made:

- The reinstated bed behind the weir should make use of material larger than the D50 grain size to reduce the risk of scour behind the structure. The smaller size fraction should be used as a top dressing.
- The design should look to minimise disturbance to any of the existing large boulders in this area which will further help to protect the upstream face of the structure.
- The pipe crossing should cite any new pillars further back from the channel edge to avoid the need for work within the channel and to mitigate for any potential future scour around the structure.

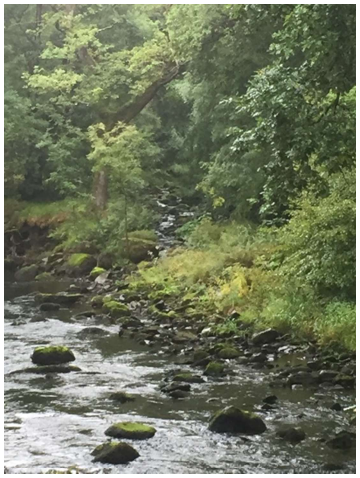
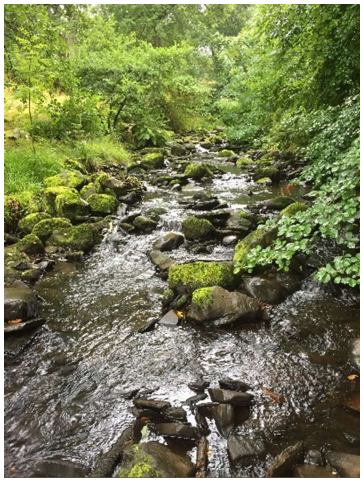
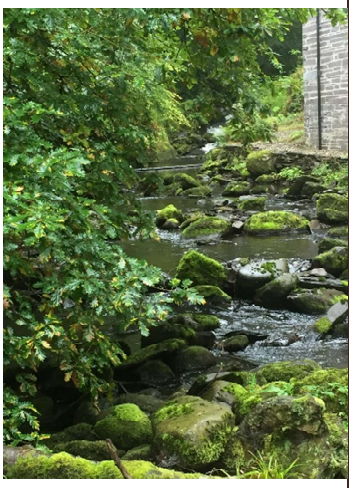
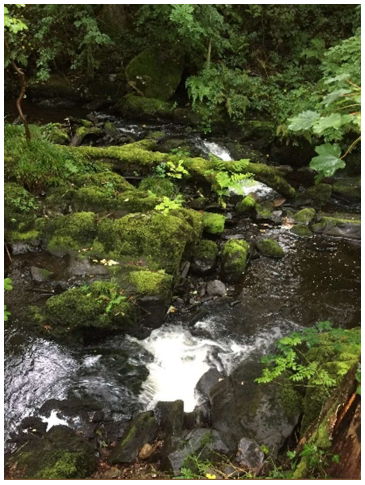
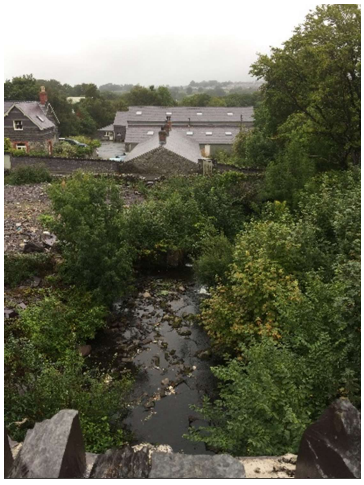
Given the following:

- The industrial heritage of the river (i.e. channel modifications);
- The proposed design of the HEP scheme, in particular the weir, which will take on a form similar to other weirs located along the channel

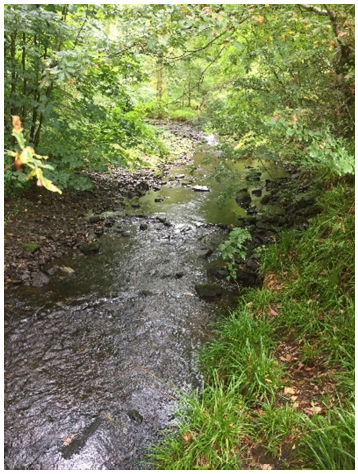
the potential for any significant cumulative impact on the Afon Galedffrwd from the proposed works is considered to be low/negligible within the overall context of this modified water body. The proposed works are unlikely to compound any existing issues in terms of sediment transport and therefore are unlikely to lead to any adverse effect on the water body or cause a risk of deterioration in terms of the existing water body WFD status.

This assessment is based on the information provided for the proposed HEP scheme, made available at the time of writing and as presented in section 3.1. Any significant changes to the design may impact on the findings presented here and therefore may require reassessment.

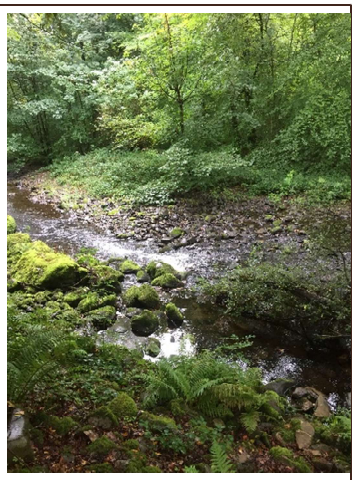
APPENDIX A: PHOTOS

Afon Galedffwd Photos 3rd Sept 2018		
		
A1. Confluence with the Afon Ogwen	A2. Downstream channel Afon Galedffrwd	A3.Moss covered boulders in downstream channel
		
A4.Moss covered boulder weirs	A5. Felin Fawr former Slate Works – view looking d/S to large weir.	A6. Felin Fawr site – channel is culverted.
		
A7. Former pipeline adjacent to the channel upstream of Felin Fawr	A8. Coed Y Parc lower dam	A9. Coed Y Parc upper dam

A10. Impounded and heavily silted channel upstream of Coed Y Parc upper dam

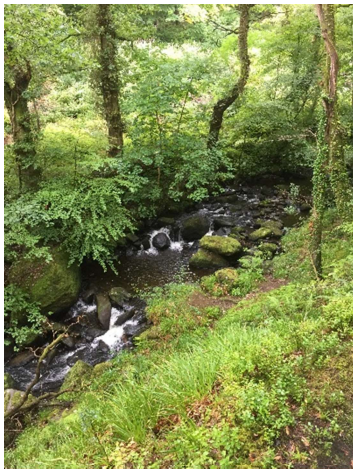
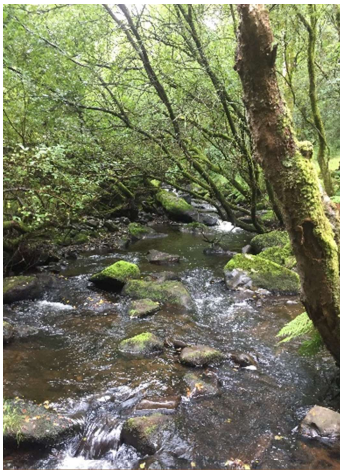


A11. Gravel bars deposited along a wider stretch of channel upstream of the impounded reach

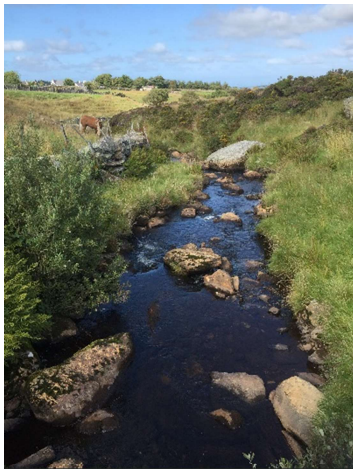


A12. Step pool channel morphology

A13. Bedrock confined stretch. Step-pool morphology. Moss covered stable boulders and finer mobile gravel bed.

		
A14. Narrow confined channel	A15. Channel upstream of footbridge	A16. Natural pools and cascades. Shaded channel.
		
A17. Approximate location of proposed weir and Intake. Small 1m high natural boulder cascade	A18. Woody debris blocked culvert under the road bridge upstream of the proposed weir and intake	A19. Macrophyte growth along a rare unshaded stretch of the channel

A20. Channel upstream of the road bridge, culvert and historic dam. Landuse rough pasture. Notably change in character as floodplain widens.

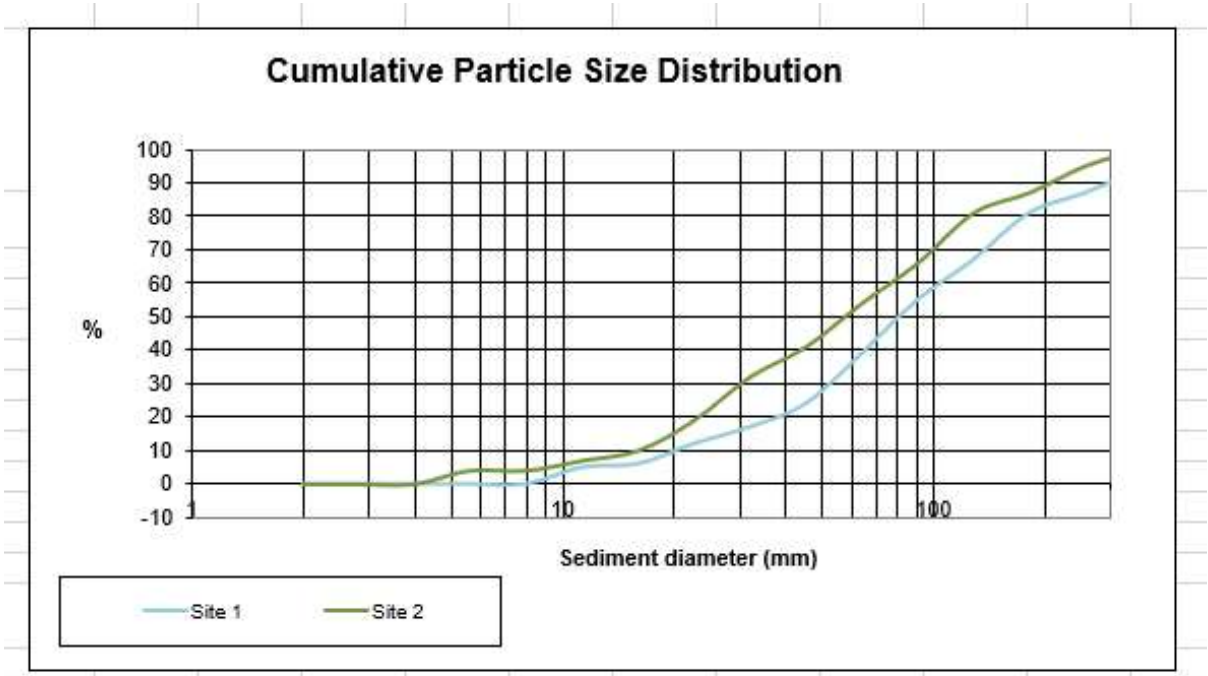


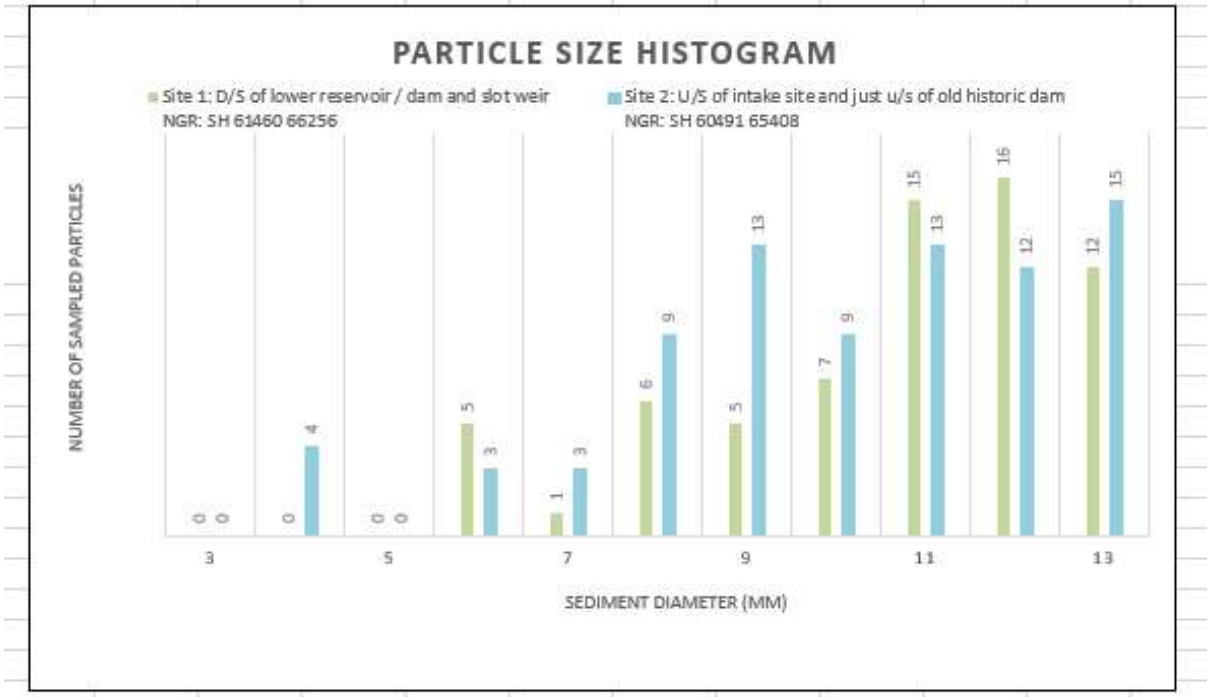
A21. Shallow boulder stream cut through heath and moorland

A22. Upstream tributary

A23. Heavily eroded banks along one of the upstream tributaries. Source of fine gravel and silt.

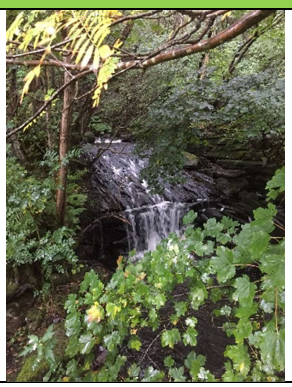
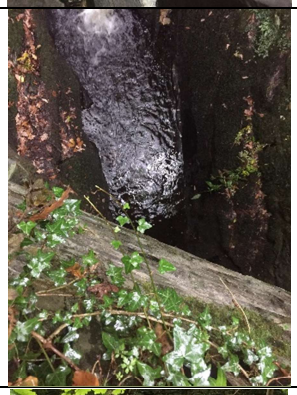
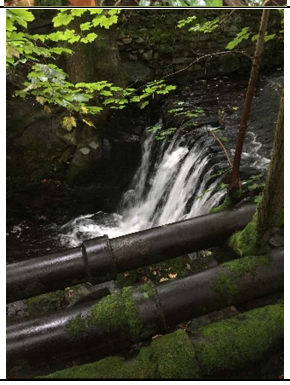
APPENDIX B: GRAIN SIZE DATA

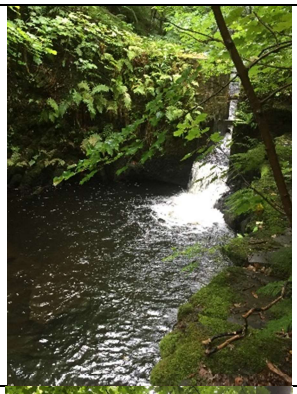
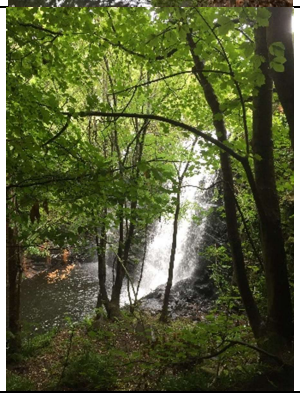
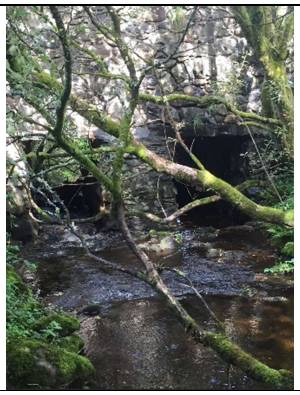

Cumulative Particle Size Distribution
100
90
80
70
60
50
40
30
20
10
0
-10
%
1
10
100
Sediment diameter (mm)
Site 1
Site 2

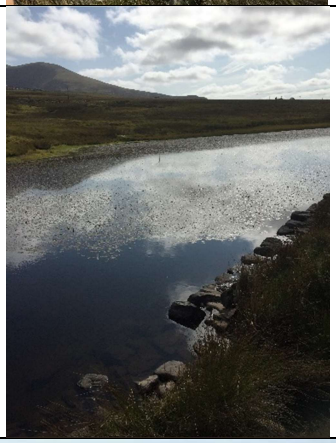
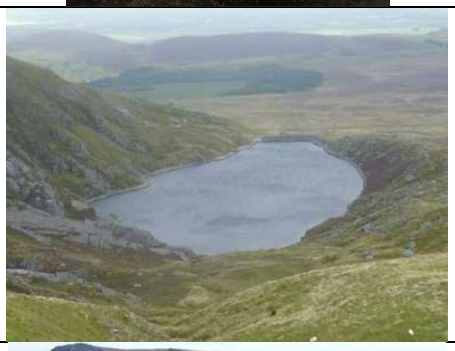

PARTICLE SIZE HISTOGRAM
Site 1: D/S of lower reservoir / dam and slot weir
NGR: SH 61460 66256
Site 2: U/S of intake site and just u/s of old historic dam
NGR: SH 60491 65408
NUMBER OF SAMPLED PARTICLES
0 0
0 4
0 0
5 3
1 3
6 9
5 13
7 9
15 13
16 12
12 15
3
5
7
9
11
13
SEDIMENT DIAMETER (MM)

APPENDIX C: EXISTING MODIFICATIONS AND HYDRO-MORPHOLOGICAL PRESSURES

Described from downstream to upstream

Ref. No.	Location	Grid Ref.	Pressure / modification	Description / Photo	Barrier to sediment transport (Y/N)
1	90m upstream from the Afon Ogwen confluence (downstream of the B4409 road crossing)	261584, 366540	Weir - 4m drop		No – bed upstream is level with the weir crest
2	B4409 road crossing	261563, 366429	Bridge	Channel under bridge not observed.	Unknown – but unlikely
3	Downstream of the Coed-y-parc (Site of the former Felin Fawr Slate Works)	261553, 366429	Weir – 6m drop		No – bed upstream is level with the weir crest
4	Coed-y-parc (Site of the former Felin Fawr Slate Works)	261506, 366349	Culvert - 215m in length		No
5	Upstream of the Coed-y-parc (Site of the former Felin Fawr Slate Works)	261472, 366280	Weir – 3.5/4m drop		No – bed upstream is level with the weir crest

6	Lower dam 30m upstream from the culvert of the former Slate Works (Coed Y Parc Reservoir)	261445, 366247	Old dam and slot weir – approx. 1m wide and 2m drop. Observed during low flow so no observed impoundment behind the dam		Yes – due to the narrow offtake through the dam
7	Upper dam 90m upstream from the culvert of the former Slate Works (Coed Y Parc Reservoir)	261412, 366196	Reservoir and dam, outlet over a large weir - 10m drop Weir impounds 100m length of channel		Yes – behind dam and within the impoundment
8	370m upstream from the culvert of the former Slate Works	261234, 366058	Stepping stones	Public footpath crosses the river (not observed)	Unlikely
9	680m downstream from Pont Galedffrwd road crossing	261091,365904	Footbridge	Public footpath crossing the river	No
10	Pont Galedffrwd road crossing	260606, 365485	Bridge and culvert (x2 openings) Minor road crossing		Yes – due to debris accumulation within both culverts
11	Pen y Bont - 65m upstream from Pont Galedffrwd bridge	260559, 365448	Historic reservoir and dam. Confined flow through a gap in the dam		Yes – though the dam is breached flow is confined to a small opening in the structure

Upstream Tributaries					
12	Head of the western tributary Llyn Newydd Historic dam and reservoir	261051, 364660	Historic reservoir and dam, breached narrow flow outlet		Yes – though the dam is breached flow is confined to a small opening in the structure
13	Eastern tributary (Afon Marchlyn-Mawr) Lyn Owen-y-ddol Historic dam and reservoir 500m upstream from Pont Galedffrwd bridge	260025, 364792	Reservoir and dam, breached weir at outlet Area 0.4ha		Yes - due to creation of an impoundment behind the dam but only at normal to low flows as the outfall is likely to be breached at higher water levels
14	Eastern tributary (Afon Marchlyn-Mawr) Marchlyn Bach Owned and operated by Welsh water to supply a water treatment works	260664,362642	Reservoir, dam and culvert Area 4.8ha		Yes – due to creation of an impoundment behind the dam
15	Eastern tributary (Afon Marchlyn-Mawr) Marchlyn Mawr Supplies water to the Dinorwig Hydro-Electric Power Station	261377, 362026	Reservoir, dam and culvert Area 26.3ha		Yes – due to creation of an impoundment behind the dam