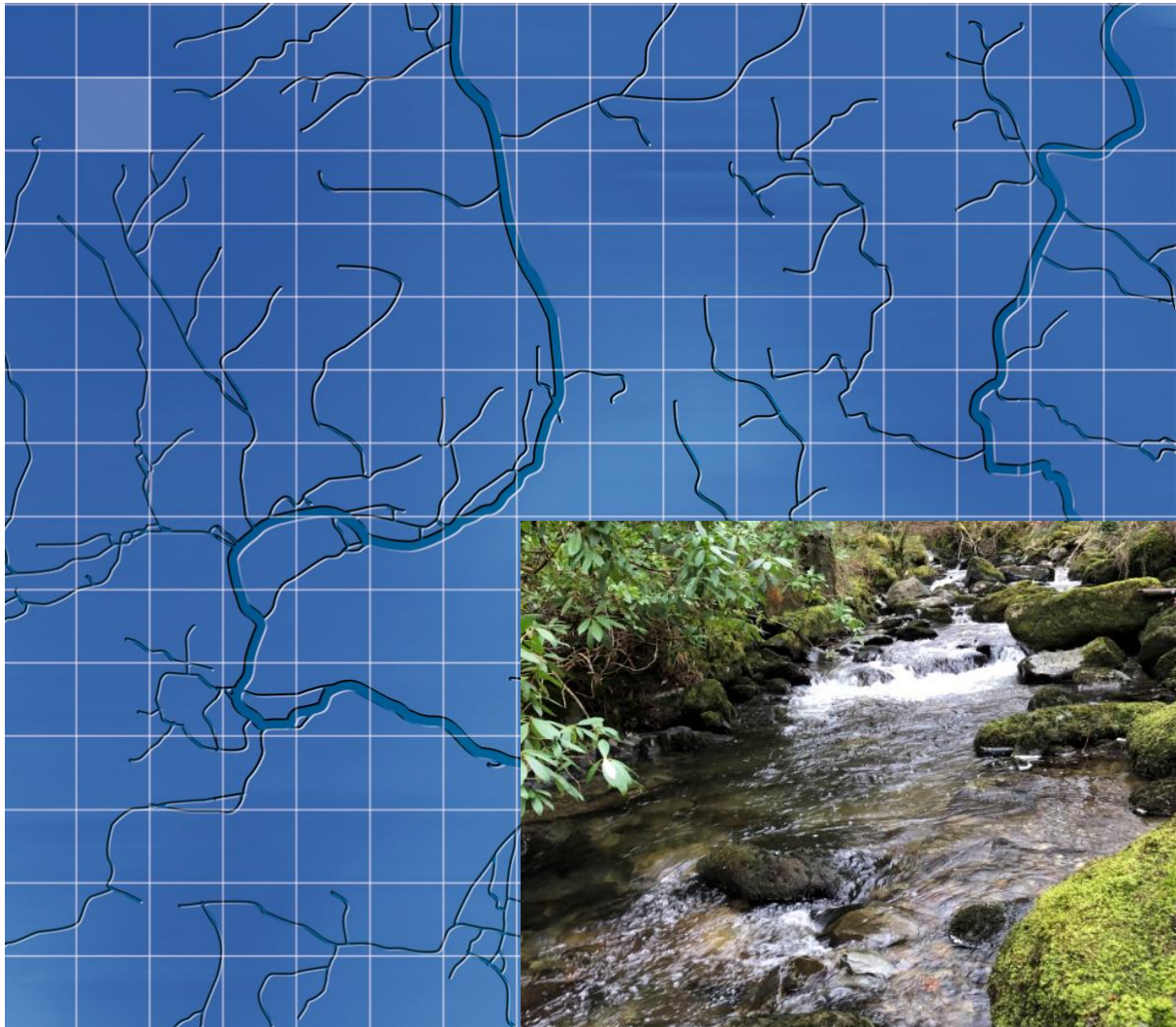


**Dolhendre Hydro Ltd**

February 2019

# **Afon Celynog Geomorphology Assessment**



**WHS**

# Dolhendre Hydro Ltd

## Afon Celynog Geomorphology Assessment

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For and on behalf of Wallingford HydroSolutions Ltd.

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## 1 Introduction

Wallingford HydroSolutions Ltd (WHS) have been commissioned by Dolhendre Hydro Ltd to undertake a fluvial geomorphological walkover survey and a quantitative assessment of sediment transport along the Afon Celynog near Dolgellau, Snowdonia (NGR: 279202, 320664). The work is required to support an application for two separate hydroelectric power (HEP) schemes along the Celynog consisting of new hydropower turbines and associated infrastructure.

A qualitative assessment was carried by Dr Lynda Yorke in July 2017. However, Natural Resources Wales (NRW) have raised concerns that the assessment did not adequately quantify the impact of the proposed schemes on the geomorphology of the Afon Celynog. NRW are also responsible for delivery of the Water Framework Directive (WFD) and further assessment needs to show that the schemes will not compromise the existing WFD compliance of the Afon Celynog. In this regard a full quantitative cumulative assessment has been requested.

## 2 Scope

The main objective of this work is to develop an understanding of the potential cumulative impacts of the schemes by carrying out a geomorphological assessment of the Afon Celynog. This will include the following:

- Grain size analysis and flow assessment to determine sediment transport processes along the proposed HEP reach.
- Assessment of the existing barriers to sediment transport along the Celynog.
- Assessment of the potential impact of the HEP proposals on sediment transport processes along the Celynog.
- Detail on the effects that the intake and discharge will have on the channel in relation to scour and deposition in a full range of flows.
- To provide, if required, appropriate recommendation for mitigation in order to achieve WFD compliance.

## 3 Methodology

Initially a desk-based assessment has been undertaken and the following data sources reviewed:

- Dr Lynda Yorke's Geomorphological Assessment of the Afon Celynog<sup>1</sup>
- Dolhendre Hydro Ltd Drawings<sup>2,3</sup>
- Lle Geo-Portal-Water Framework Directive (WFD) River Waterbodies Cycle 2 mapping<sup>4</sup>

A 400m walkover survey was conducted on the 21<sup>st</sup> January for the lower section of the Afon Celynog where the first HEP scheme is proposed, extending from the confluence with the Afon Wnion (NGR: 279194, 320700) to the arch road bridge which transverses the river at NGR 279509, 320447. A second walkover survey was conducted on 28<sup>th</sup>-29<sup>th</sup> January of the middle section of the Afon Celynog where the second HEP scheme is proposed, extending from the arch road bridge to the proposed intake of the new scheme at NGR:280247, 320191. It was not possible to survey the upper reaches

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<sup>1</sup> Dr Lynda Yorke (2017) Geomorphological Assessment: Afon Celynog, Afon Celynog Geomorph Assessment.pdf

<sup>2</sup> A0.1 (2018) Intake Dimensions and General Arrangement (Scheme B)

<sup>3</sup> A0.1 (2018) Intake Dimensions and General Arrangement (Scheme C)

<sup>4</sup> Lle (2019) WFD River Waterbodies Cycle 2 mapping, <http://lle.gov.wales/map>, accessed 30/01/19

of the Afon Celynog where an existing Snowdonia Hydro HEP scheme has been installed, due to problems with access and adverse weather conditions.

Geo-referenced photographs were taken of features along the length of the river with detailed notes taken on the channel form, floodplain and bedload characteristics at the inflow and outfall locations of the two schemes.

Sediment grain size samples were taken at the intake and outfall locations of the proposed HEP schemes. The Wolman pebble count procedure was used which records the size of 100 sediment particles randomly selected in transects across the river's width. The  $D_{50}$  and  $D_{84}$  grain sizes were subsequently estimated at each location, and the Hjulstrum curve method used to estimate the likely threshold velocity required to initiate sediment transport for both grain size classifications.

Bankfull area was also estimated at each of the sites using the velocity-area method and this multiplied by the threshold velocity to determine the critical discharge.

The weather conditions during the site walkover on the 21<sup>st</sup> January were cloudy with light rain showers, the survey followed a period of generally dry weather. The survey from 28<sup>th</sup>-29<sup>th</sup> January were cloudy with snow showers, the survey followed a period of generally wet weather.

## 4 The Schemes

Two additional HEP schemes are proposed in the middle and lower reaches of the Afon Celynog respectively. These will add to the existing Snowdonia Hydro scheme in the upper reaches of the Celynog.

The HEP scheme in the middle reaches (Scheme B) is proposed to abstract water from the Celynog at NGR: 280247, 320191, discharging flows downstream at NGR: 279514, 320441. The general arrangement of the scheme includes a reinforced concrete weir with a crest elevation set at 216.35 m AOD. The full width of the structure (weir and screen) will be 5m, it will have a plunge pool immediately downstream which will be 300mm minimum depth. The proposals also include a ramped fish pass. The maximum design abstraction rate will be 193 l/s, and the agreed hands off flow (HOF) will be 27 l/s, with the scheme designed to ensure that it will not abstract more than 40% of the available flow.

The intake at scheme C will be located at an existing weir. The existing weir will be removed and a broad crested weir installed. The new weir will maintain the existing crest height to ensure there are no impacts on water level. The crest height will be 135.40 m AOD and the structure width will be 8.20m. A rocky ramped fish pass is also to be created. The maximum design abstraction rate will be 369 l/s, and the agreed HOF will be 41 l/s, with the scheme designed to abstract a maximum of 40% of available flow.

Please see Appendix 1 for scheme drawings.

## 5 Catchment Overview

The catchment of the Afon Celynog is approximately 6.8 km<sup>2</sup> and is located in the south east of the Snowdonia National Park. The catchment rises on the north western side of Glasgwm at approximately 650 m above sea level and flows in a westerly direction draining into the Afon Wnion south west of Rhydymain. A number of spring fed tributaries at the head of the catchment feed into the Afon Celynog watercourse.

The catchment is typical of an upland stream, it is horizontally and vertically stable with the watercourse entrenched within its valley and relatively little floodplain. The gradient in the upper reaches is shallower relative to the lower reaches and has a meandering nature. In the middle reaches the majority of the channel bed consists of boulder deposits and bedrock benches which create a step pool profile. However the channel does enter a gorge feature approximately 200m upstream of the arch road bridge (NGR: 279509, 320447), where a cascade profile is observed. The channel profile briefly flattens downstream of the arch bridge and existing weir structure where the intake of scheme C is proposed before entering a second gorge. As the river approaches the Wnion confluence it flattens slightly with step pool sequences prevalent.

In terms of geology, the upper reaches are shown to vary from the lower reaches. The Celynog comprises a mixed bedrock-alluvial channel, whereas the lower reaches are underlain by outcropping bedrock, with boulders that are likely relic of glacial transport processes that do not move under normal flow conditions. The Celynog flows over Felsic Tuff, Siltstones/Tuffaceous Siltstone and volcanic Siltstones, as well as Mudstones.

The land use of the Celynog catchment is predominantly rural, with the upper reaches draining open moorland and agricultural land. The land use is similar at the lower reaches with the exception of a few agricultural buildings. There are no named villages within the catchment.

The groundwater vulnerability map published by the British Geological Survey shows the catchment of the Celynog is underlain by a secondary aquifer. This is assessed as being at medium to high risk in terms of groundwater vulnerability.

Field notes and key photographs collected during the site walkover are provided in Appendix 2.

## 6 Water Framework Directive Status

The WFD aims to protect and improve the water environment by setting objectives to achieve good qualitative and quantitative status for all water bodies. Watercourses are assessed in terms of biological, physical and chemical elements, with objectives set for specific areas by River Basin Management Plans (RBMP). The Afon Celynog itself has not been included in the Cycle 2, 2015 classification. Unclassified water bodies should be assessed against the classification given for the closest adjacent water body. For the Celynog this is the upper Wnion river. The review of this waterbody in the latest 2015 RBMP cycle 2 update shows that the watercourse has "good" WFD status for both ecological and chemical status. The river is also not classed as being a heavily modified water body (HMWB).

### 6.1 Channel Gradient

The Afon Celynog channel has a steep gradient, with an average slope of 0.30 based on available OS Terrain 50 data for the reach. Aforementioned cascade and step pool sequences dominant the majority of the river's length.

## 6.2 Channel Banks

Large boulders and bedrock outcrops make up the channel banks in many locations, particularly in the lower and middle reaches. The banks in these locations are vegetated by sometime dense deciduous forest through the middle reaches. Further upstream where the channel opens out into moorland, the floodplain is slightly less steep, however the channel remains largely confined.

## 6.3 Grain Size Analysis

### 6.3.1 Scheme B

Table 1 shows the results of the sediment grain size analysis at Scheme B.

**Table 1 - Scheme B Grain Size Analysis**

Location	NGR	D <sub>50</sub> (mm)	D <sub>84</sub> (mm)	Site Description
Site 1: Proposed Outfall Scheme B	279514, 320441	56	159	Coarse gravel bedload with many large boulders, very steep floodplain with deciduous woodland
Site 2: Proposed Inflow Scheme B	280247, 320191	45	108	Coarse gravel bedload, some boulders confined floodplain with moorland present

The bedload of the channel at both the inflow and outfall locations is coarse ranging from medium sized gravel near the channel banks where stream energy is low to large cobbles/small boulders in the thalweg where stream energy is highest. The median grain size (D<sub>50</sub>) is characteristic of medium to large pebbles and the D<sub>84</sub> is defined as cobbles at both locations.

The channel gradient at the inflow location (site 2) is less than the gradient at the outfall location (site 1). This is expected to result in slightly lower flow velocities increasing the deposition of finer gravel and leading to the lower D<sub>50</sub> value estimated for the inflow reach.

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 watercourse.

Figure 1 shows the cumulative particle size distribution at each of the sites.

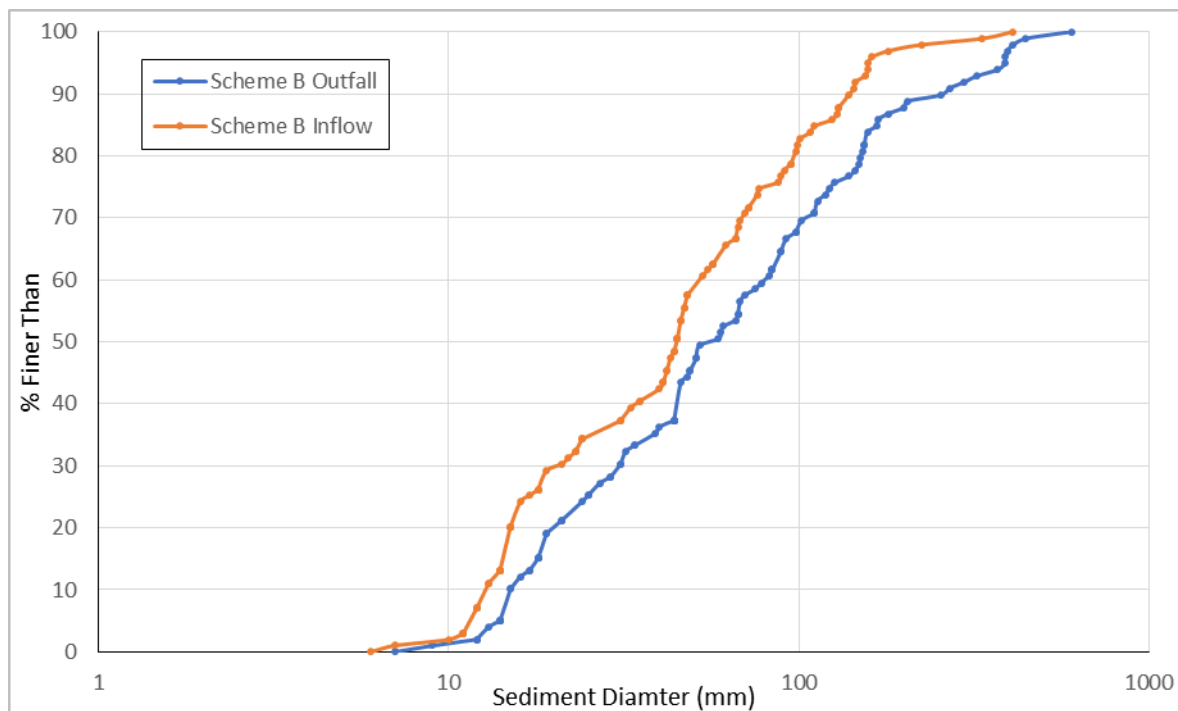


Figure 1 - Cumulative particle size distribution - Scheme B

### 6.3.2 Scheme C

Table 2 shows the results of the sediment grain size analysis at Scheme C.

Table 2 - Grain size analysis - Scheme C

Location	NGR	D <sub>50</sub> (mm)	D <sub>84</sub> (mm)	Site Description
Site 1: Proposed Outfall Scheme C	279202, 320664	59	174	Coarse gravel bedload with many large boulders, steep floodplain with deciduous woodland
Site 2: Proposed Inflow Scheme C	279481, 320449	35	80	Medium gravel bedload, confined floodplain with deciduous woodland

The sediment size at the outfall location of scheme C varied from small sized gravels to large cobbles/small boulders. The D<sub>50</sub> for the outfall was in the moderate to large sized pebble region. The sediment at the proposed inflow is finer and dominated by small to medium sized pebbles. In terms of the D<sub>84</sub>, it is significantly larger at the outfall where there are far more boulder deposits.

The observed differences in the sediment size between the two locations are likely caused mainly by differences in slope. The inflow location is located in a relatively flat reach, and the impoundment caused by the existing weir structure has caused an accumulation of finer sediment. The outfall location is steeper and characterised by a number of boulder weirs and faster flows. Figure 2 shows the cumulative particle size distribution.

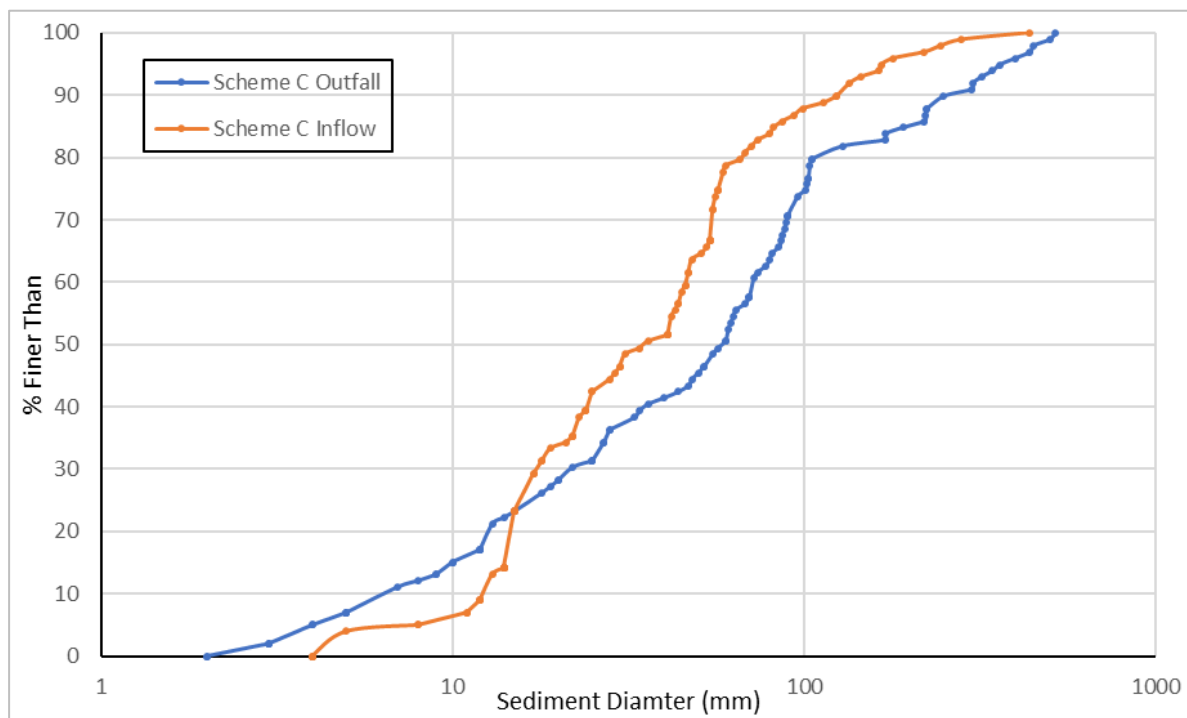


Figure 2 - Cumulative particle size distribution - Scheme C

## 6.4 Sediment Transport

### 6.4.1 Scheme B

Sediment transport calculations have been used to determine the potential thresholds for sediment transport along the Afon Celynog. This will help inform whether the existing bed substrate is able to be mobilised and if so how frequently based on available flow data.

The Hjulstrum curve method has been applied to achieve this. The graph allows estimation of the flow velocity required to initiate sediment transport based on grain size. The graph gives a minimum and maximum velocity for each grain size, these have been estimated for both the D<sub>50</sub> and D<sub>84</sub> grain sizes at each of the sites.

Bankfull area calculated at each of the sites was then multiplied by the minimum, average and maximum threshold velocity to determine the range of critical entrainment discharges (Q<sub>crit</sub>). The scheme B results for both the D<sub>50</sub> and D<sub>84</sub> grain sizes are shown in Table 3 and Table 4 respectively. Appendix 3 provides the raw site data used to calculate bankfull area.

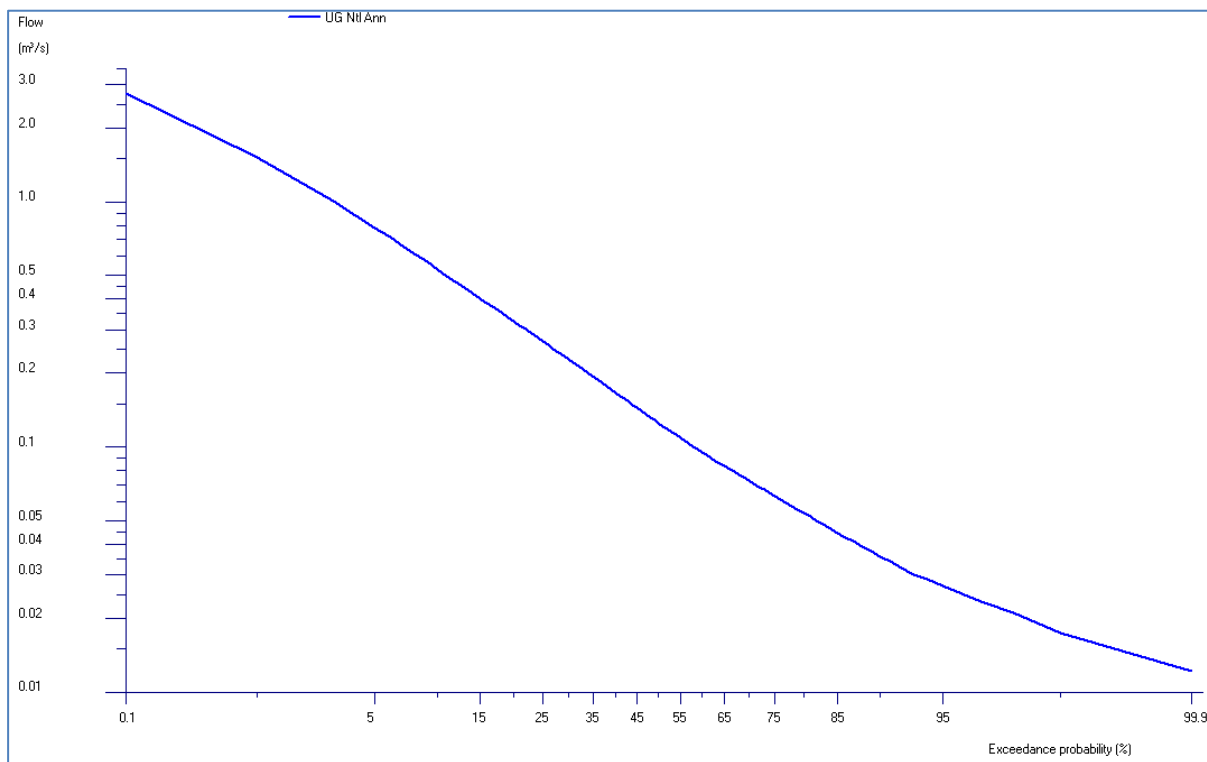
**Table 3 – Scheme B  $Q_{crit}$  calculations for the  $D_{50}$  grain size**

Sediment movement threshold to initiate transport (Hjulstrum method)				Sediment movement discharge $Q_{crit} = VA$		
Location	$D_{50}$ (mm)	Min Velocity (m/s)	Max Velocity (m/s)	Bankfull Area (m <sup>2</sup> )	Min-Max (m <sup>3</sup> /s)	Average (m <sup>3</sup> /s)
Site 1: Proposed Outfall Scheme B	56	0.70	2.90	2.84	1.99 – 8.24	5.11
Site 2: Proposed Inflow Scheme B	45	0.65	2.60	2.31	1.50 – 6.01	3.75

**Table 4 - Scheme B  $Q_{crit}$  calculations for the  $D_{84}$  grain size**

Sediment movement threshold to initiate transport (Hjulstrum method)				Sediment movement discharge $Q_{crit} = VA$		
Location	$D_{84}$ (mm)	Min Velocity (m/s)	Max Velocity (m/s)	Bankfull Area (m <sup>2</sup> )	Min-Max (m <sup>3</sup> /s)	Average (m <sup>3</sup> /s)
Site 1: Proposed Outfall Scheme B	159	1.20	4.00	2.84	3.41 – 11.36	7.38
Site 2: Proposed Inflow Scheme B	108	1.05	3.90	2.31	2.43 – 6.21	5.72

The  $Q_{crit}$  values calculated are compared to available flow data to identify the likelihood of bed material being dislodged and transported. Due to the unavailability of observed gauge data within the vicinity of the site, flow estimates have been calculated using the LowFlows Enterprise software with flow duration curves produced. This has been carried out for both the  $D_{50}$  and  $D_{84}$  calculations. Figure 3 shows the flow duration curve at the inflow location.

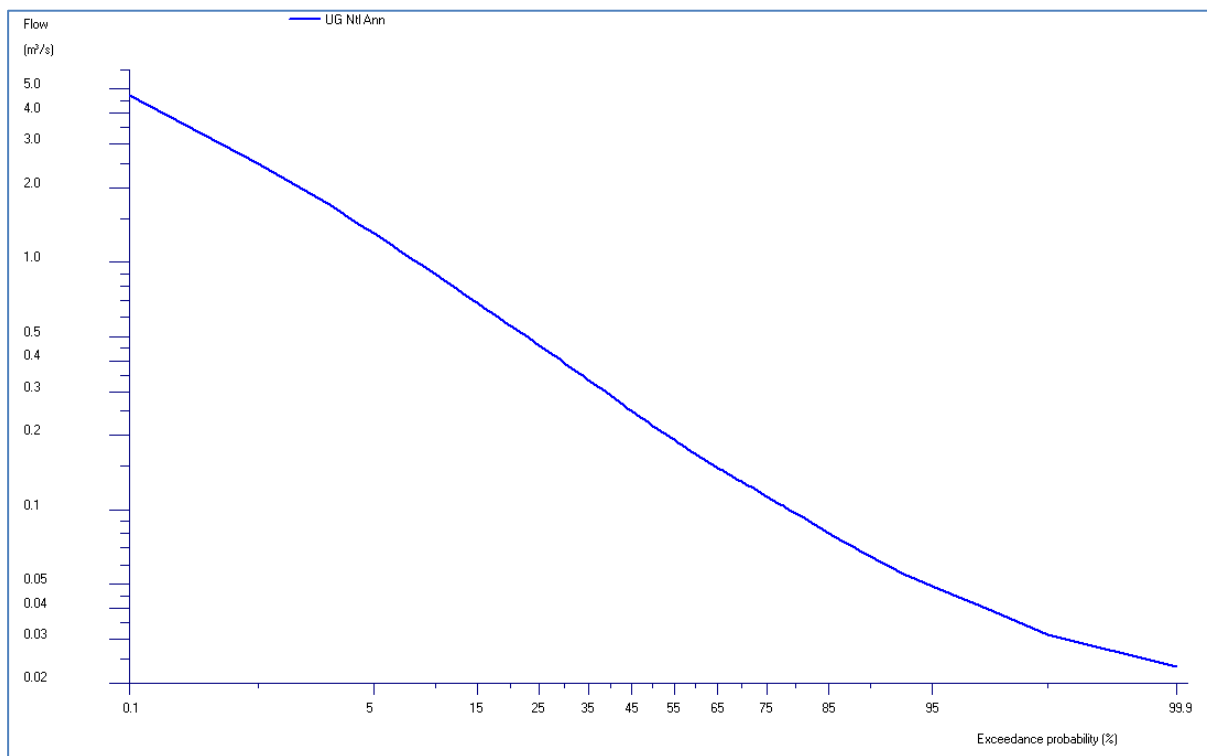


**Figure 3 – Natural flow duration curve - Scheme B inflow (LowFlows Enterprise)**

For the D<sub>50</sub> grain size at the inflow location, both the average and maximum Q<sub>crit</sub> values are shown to be extremely rare events. LowFlows does not estimate extreme flood flows however based on the flow duration curve derived, the average and maximum Q<sub>crit</sub> flows are higher than the Q<sub>0.1</sub> and would not be exceeded for at least 99.9% of the year. The minimum Q<sub>crit</sub> value of 1.5m<sup>3</sup>/s is equivalent to the Q<sub>2</sub> flow. This would be a high flow event and the results indicate that no sediment transport occurs under normal flow conditions, with the median flow (Q<sub>50</sub>) of 0.15m<sup>3</sup>/s far below the threshold discharges calculated.

For the D<sub>84</sub> grain sizing at the inflow location, both the average and maximum calculated Q<sub>crit</sub> values show as extremely rare events once again in excess of the Q<sub>0.1</sub> flow. The minimum Q<sub>crit</sub> value for the D<sub>84</sub> grain sizing approximately equivalent to the Q<sub>1</sub> flow.

The same analysis has been applied at the outfall location. Figure 4 shows the flow duration curve at the outfall location.



**Figure 4 – Natural flow duration curve for Scheme B outflow, Scheme C inflow and Scheme C outflow (LowFlows Enterprise)**

For the D<sub>50</sub> grain size, similar to the inflow, both the average and maximum Q<sub>crit</sub> values are shown to be extremely rare events. Based on the flow duration curve derived, the average and maximum Q<sub>crit</sub> flows are higher than the Q<sub>0.1</sub> and would not be exceeded for at least 99.9% of the year. The minimum Q<sub>crit</sub> value of 1.99m<sup>3</sup>/s however is shown to be approximately equivalent to the Q<sub>3</sub>, so there is potential for this grain size and finer sediment to be transported during high flow events. The median annual flow at the outfall is approximately 0.23m<sup>3</sup>/s, therefore no sediment transport is expected under normal flow conditions.

The D<sub>84</sub> reflects the same pattern as at the inflow, where there is a small chance of transport during very high flow events when considering the minimum Q<sub>crit</sub> value, which is approximately equivalent to the Q<sub>0.5</sub> event. No movement is predicted for the average and maximum Q<sub>crit</sub> values.

**6.4.2 Scheme C**

The same method has been applied to obtain the Q<sub>crit</sub> values and potential for sediment transport at Scheme C. These are provided in Table 5 and Table 6.

**Table 5 - Scheme C  $Q_{crit}$  calculations for the  $D_{50}$  grain size**

Sediment movement threshold to initiate transport (Hjulstrum method)				Sediment movement discharge $Q_{crit} = VA$		
Location	$D_{50}$ (mm)	Min Velocity (m/s)	Max Velocity (m/s)	Bankfull Area (m <sup>2</sup> )	Min-Max (m <sup>3</sup> /s)	Average (m <sup>3</sup> /s)
Site 1: Proposed Outfall Scheme C	58.50	0.73	2.95	6.40	4.67 – 18.88	11.78
Site 2: Proposed Inflow Scheme C	35.00	0.55	2.40	2.89	1.59 – 6.94	4.26

**Table 6 - Scheme C  $Q_{crit}$  calculations fo the  $D_{84}$  grain size**

Sediment movement threshold to initiate transport (Hjulstrum method)				Sediment movement discharge $Q_{crit} = VA$		
Location	$D_{84}$ (mm)	Min Velocity (m/s)	Max Velocity (m/s)	Bankfull Area (m <sup>2</sup> )	Min-Max (m <sup>3</sup> /s)	Average (m <sup>3</sup> /s)
Site 1: Proposed Outfall Scheme C	174.36	1.45	4.15	6.40	9.28 – 26.56	17.92
Site 2: Proposed Inflow Scheme C	80.32	0.90	3.30	2.89	2.60 – 9.54	6.07

The flow duration curve shown in Figure 4 is representative of flows at the inflow location given its proximity to scheme B’s outfall. Further analysis also showed that there was a negligible difference in catchment area between the outfall and inflow structures for scheme C with no significant difference in flows as a result. Therefore the flows in Figure 4 are used to assess the potential for sediment transport at the proposed outfall location.

At the inflow location for scheme C, sediment transport appears to be more frequent than at the other sites. The  $D_{50}$  grain size is slightly finer, which leads to the average  $Q_{crit}$  being equivalent to the Q5 and the minimum  $Q_{crit}$  aligning with the Q6. No sediment transport is predicted across the range of estimated flows when considering the maximum  $Q_{crit}$  value.

For the  $D_{84}$  grain size sediment transport the minimum  $Q_{crit}$  flow is equivalent to the Q2 flow, however the other  $Q_{crit}$  values are higher than the Q0.1 flow.

In general the movement of bedload at the intake is considered to be possible during medium to high flow events, however it remains unlikely that the  $D_{84}$  grain size will be frequently mobilised.

At the outflow location, all  $Q_{crit}$  values, with exception of the minimum calculated for the  $D_{50}$ , are shown to be for extreme events significantly above the Q0.1 flow. The minimum  $Q_{crit}$  for the  $D_{50}$  aligns with the Q0.1 flow. Therefore, significant sediment transport is likely to be very rare at the outflow location.

## 7 Impact Assessment

### 7.1 Outline

To assess the impact of the proposed HEP schemes on the Afon Celynog, their impact is assessed in the context of existing structures and modifications identified along the watercourse during the site walkover. From an ecological standpoint, the potential impact of HEP schemes is principally on flow and sediment transport. Sediment serves as the basis for soils and landforms alike, and its transport plays a key role in carrying nutrients and facilitating chemical reactions.

The impact assessment therefore primarily focuses on sediment transport processes along the Afon Celynog, using the data analysis applied in section 6.4 and reviewing the existing geomorphological pressures which are present along the reach.

### 7.2 Impact of existing structures

Six existing man-made structures were identified along the Afon Celynog, comprising 3 bridge structures, 2 weirs and 1 outfall structure. Aforementioned it was not possible to survey the Snowdonia Hydro HEP scheme in the upper reaches of the river, which comprises an additional weir feature and outfall structure. The impact of the scheme has been assessed based on the abstraction and impoundment licenses for the scheme which have been provided by NRW and intake plans provided by the client. The locations of the structures are shown in Figure 5. A summary is provided in Table 7 with further detail provided in Appendix 4.

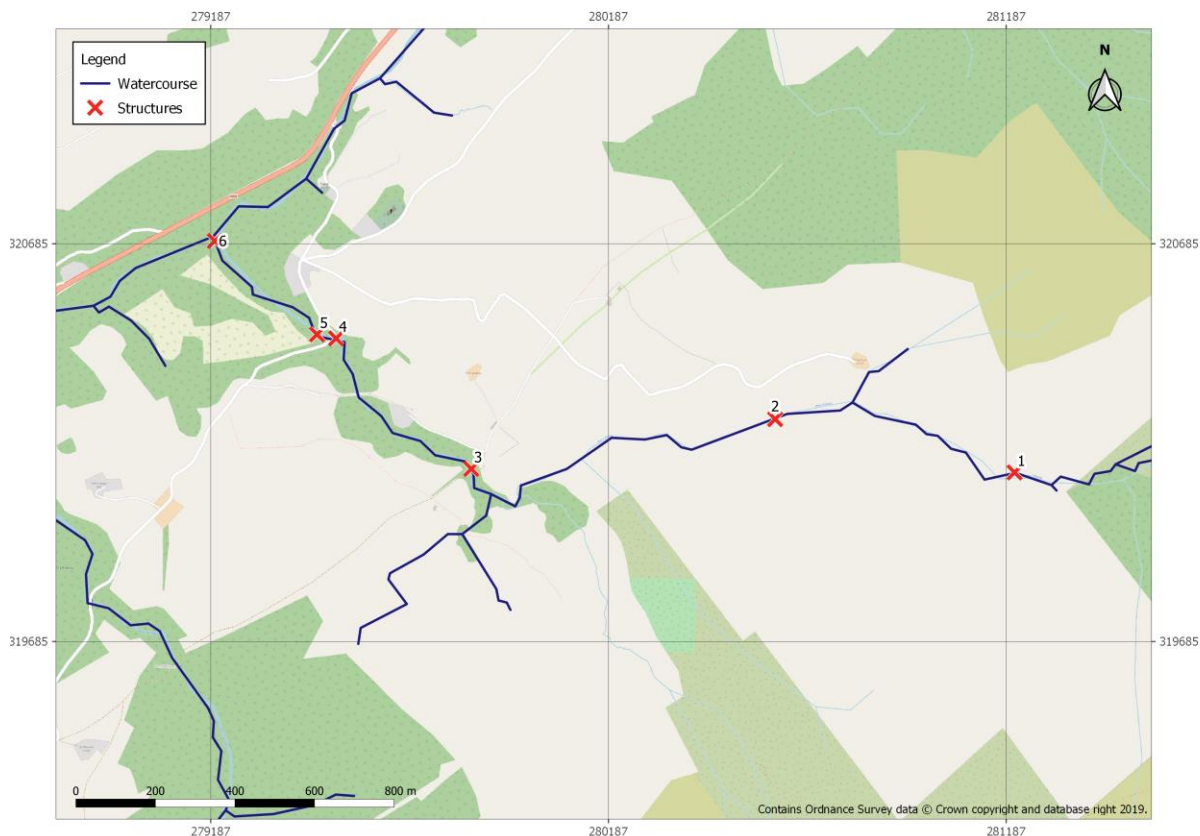


Figure 5- Location of existing structures along the Afon Celynog

**Table 7- Summary of channel modifications identified along the Afon Celynog**

Structure	Number	Barrier to Sediment Transport
Weirs	2	Potential barriers to bedload transport
Bridges	3	Some localised impacts
Outfall Structure	1	No impacts expected

The 3 bridge structures (3, 4 and 6) are all single arch bridges, which are similar in terms of design. The structures cause a narrowing of the river channel with the abutments of each bridge partially submerged during the site visit. When a structure such as a bridge is placed in a stream, there is a local loss of stream energy. This is due to the fluid friction in contact with the structure and the stagnation zones that border the contracting and expanding flow reaches up and downstream of the structure. It is therefore possible that the 3 arch bridges identified during the site walkover have some impact on sediment transfer through the reach. The impacts are expected to be localised to the stagnation zones near abutments for the majority of flows. Finer sediment deposition was noted in these locations due to the slow flow conditions during the site walkover. Despite these localised impacts the opening ratio (the ratio of the structure’s open area to the flow area at a particular water level) is expected to be relatively high for the bridges identified across a range of flows. Therefore the majority of sediment should be able to pass beneath the structures without obstruction and sediment supply to downstream reaches should not be significantly reduced for most events.

In terms of a backwater effect, the soffit levels for the bridges are a reasonable distance above the river bank, however the backwater effect may be significant during very high flows. This may cause pooling and subsequent deposition upstream. However it should be noted that the reach is very steep, particularly upstream of structures 3 and 4, which will limit the extent of any backwater effect in these locations.

In terms of the 2 weir structures, one is the Snowdonia Hydro HEP intake (structure 1) and the second is an existing weir and fish ladder structure at the outlet of the upper gorge (structure 5). The HEP weir is a concrete broad crested weir with a compensation flow V notch, an eel pass and a rocky pool pass for fish. The impoundment caused by the weir may slow flows from upstream, causing some finer sediment to be deposited behind the weir and temporarily stored before the next high flow event. However its impact on sediment transfer is less significant in a reach such as the Celynog. No sediment transfer is expected to occur during normal flow conditions and sediment is currently temporarily stored along the channel between high flow events by natural barriers such as rock steps and large boulders in the channel. The overall impact of the weir should therefore be small delaying sediment transfer rather than altering the distribution of sediment throughout the reach.

The weir at the outlet of the upper gorge is an ogee weir. The weir has been in place for close to 100 years and utilised a natural rock step within the reach. During the site walkover it was noted that in the pool upstream of the structure there is some finer sediment which has been deposited upstream of the weir. However the weir is not considered to be a major barrier to sediment transport downstream, the weir crest sits only slightly above the upstream bed and sediment should still be transported beyond the weir during high flow events.

The outfall structure for the existing Snowdonia HEP scheme (structure 2) is not thought to have a significant impact on flow or sediment transport processes. Significant sediment transport only occurs

during high flow events, during which discharges from the outfall structure will be insignificant compared to flows in the Celynog. The orientation of the structure should also be parallel to the channel banks in order to further safeguard against erosion and scour.

In summary there are 6 identified structures/modifications already located along the Afon Celynog. Of these, only the two weir structures are likely to form significant barriers to sediment transport, although their impact is expected to be to delay sediment transfer rather than alter the sediment distribution across the reach.

### 7.3 Impact of existing structures on proposed HEP Scheme

Sediment transport calculations supported by observations from the geomorphological survey of the reach indicate that sediment transport is limited along the Afon Celynog. Aforementioned, the bed of the channel appears to be stable, confined either by bedrock or by large boulders that are unlikely to be mobilised. Some sediment transport may occur for finer gravel sediment and small to medium sized pebbles, but this will be limited to high flow events.

The proposed HEP works will however create further structures along the channel, further modifying flow and still having potential implications for sediment transport when it does occur. In this regard it is important to first assess the location of the HEP scheme in relation to the existing structures along the reach and determine whether these will firstly have an impact on the proposals and secondly whether the proposals could act to compound existing pressures caused by these structures.

#### 7.3.1 Scheme B

The proposed HEP weir and intake for scheme B will be located approximately 450m downstream of the outfall structure of the Snowdonia Hydro scheme (structure 2) and 1.1 km from the existing intake structure (structure 1). This is a significant distance and a number of step-pool sequences separate the two schemes. The closest structure downstream is the arch bridge at NGR:279833, 320112 (structure 3), which is approximately 580m downstream of the intake location. Given the distance of the intake location from these structures combined with the steepness of the channel the influence of the bridge and outfall on flow and sediment transport at the HEP intake is expected to be negligible. The intake of the existing Snowdonia HEP scheme may serve to delay sediment transfer to a degree, but this impact will be insignificant in relation to the proposed intake reach.

The outfall structure is located a short distance upstream of the arch road bridge at NGR: 279509, 320447 (structure 4). The impact of this bridge on the outfall structure is expected to be minimal, as the reach in this location is steeply sloping and characterised by step-pool features which reduce the extent of any backwater effect upstream. However the outfall structure could have an impact on finer sediment which accumulates at the bridge abutments if erosion controls aren't in place. This is covered in more detail in section 7.4.2.

#### 7.3.2 Scheme C

The proposed HEP weir and intake will be sited at the location of the existing Ogee weir which is approximately 30m downstream of the arch road bridge (structure 4). The bridge may have a small impact on sediment transfer given the short distance between the two structures, with localised accumulation of finer sediment close to the bridge abutments. However as the intake is replacing the existing Ogee weir, the current functioning of the reach is unlikely to change significantly, especially given that the existing water level will be retained.

The outfall structure will be located a short distance upstream of the arch bridge at NGR: 279200, 320679 (structure 6). Again the reach is very steep in this location, therefore the bridge is unlikely to have an impact on the outfall structure. However, the outfall structure could have an impact on finer sediment which accumulates at the bridge abutments if erosion controls aren't in place.

On the whole given the general steepness of the reach and the distances between existing/proposed structures the impacts of existing structures on the proposed HEP schemes are thought to be mostly insignificant. However, the two outfall structures could have an impact on sediment transfer of finer sediment which accumulates at the bridge crossings immediately downstream if discharges are not properly managed. These concerns are assessed in more detail in section 7.4.

### 7.4 Potential Impacts of Scheme B

The proposed HEP schemes have the potential to cause both direct and indirect impacts on the water body, which need to be assessed to determine if there are any adverse effects on a water body or the potential to cause a deterioration in WFD status. The following modifications have been assessed for each scheme in detail:

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

The impact of these modifications for scheme B are discussed below.

#### 7.4.1 Weir and Fish Pass

The proposed weir will act to impound flows upstream of it causing a fall in flow velocity, and also serve to increase flow velocities immediately downstream as flows pass over the weir crest. Significantly the structure is utilising a natural step and pool sequence, where there will already be a natural slowing of flow velocities in the pool feature followed by a subsequent increase in velocity as flows pass over the step feature.

The proposed weir height will increase the height of the natural pool and form a uniform barrier to flow across the whole river section which will modify flows to a degree. The impoundment may affect the boulder weir immediately upstream, however given the steep channel gradient it is considered highly unlikely that the water will be backed up significantly beyond the extent of the current pool feature. Instead the impoundment is likely to be very localised in extent and should not have any significant impact on the upstream channel and adjacent land use.

The changes in water levels upstream of the weir are expected to be largely insignificant, however the weir could still limit sediment transfer downstream. Firstly the weir will reduce flow velocities upstream of it causing the deposition of finer sediment. As the structure is utilising a natural step and pool sequence, flows are already slowed upstream of the step leading to the deposition of finer sediment in the pool feature, so the comparative impact of the scheme on existing flow velocities may be small. However a second characteristic of the weir is that it will form a barrier of uniform height across the river section, which could inhibit bedload transport downstream.

A potential option to reduce this impact is to backfill the area immediately behind the weir with retained gravel up to the level of the weir crest. This would ensure that the bed profile is maintained so sediment transfer processes would be unaffected. The reinstated bed should be made up of material larger than the  $D_{50}$  grain size to prevent the regular suspension of material damaging the weir crest. This measure is not considered essential given that the proposed intake location is some distance from existing structures, which lessens its cumulative impact.

The weir may also cause an increase in flow velocities immediately downstream of it. However flow velocities are already high over the existing step feature and dissipate quickly in the subsequent pool. The weir is not expected to change the current hydraulic situation significantly and should not drive a substantial increase in sediment transfer to the downstream reach.

### **7.4.2 Reinstatement of flow through the outfall**

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. The transport of most grain sizes in the outfall reach is likely to only occur during high flow events, during which discharges from the outfall structure will be insignificant compared to flows in the Celynog. However finer sediment is likely to accumulate at the abutments of the arch road bridge downstream (structure 4). Potential options to limit the potential for erosion and scour of this finer material is to discharge water onto a water bedrock cascade or use baffles in the outfall channel to reduce flow velocities from the outfall structure. The discharge outfall structure should also be placed as parallel to the channel banks as possible to limit the potential for erosion of the banks also.

### **7.4.3 Abstraction/Reduced flow within the flow depleted reach**

A proportion of the flow from the Afon Celynog will be routed into the intake and pipeline through to the turbine before rejoining the channel approximately 1.0 km downstream. This will in turn reduce the available flow within the Afon Celynog forming a flow depleted reach.

Currently it is proposed that the scheme will abstract water all year round at an instantaneous rate not exceeding 193 l/s.

The Hands of Flow (HOF) has been agreed as 27 l/s. 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 has been agreed as a percentage of 40% taken above the HOF, with 60% remaining within the reach. This ratio is to be maintained by an open rectangular notch 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 1.0 km 'flow depleted' reach is appropriately assessed.

Given the baseline understanding of the reach downstream of the intake and weir, with its steep, cascade and 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 and other bryophytes) 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 scheme.

## 7.5 Potential Impacts of Scheme C

### 7.5.1 Weir and Fish Pass

The intake weir for scheme C is replacing an existing Ogee weir, therefore it is unlikely to lead to a significant change in the current functioning of the reach. The proposals will ensure that the water level upstream remains the same and there should be little change in the existing pool upstream.

The new weir will be broad crested with a more pronounced fall in water level when compared to the sloped Ogee weir currently in operation. This may cause a small increase in flow velocities immediately downstream of it. However flow velocities are already high over the existing weir and dissipate quickly in the subsequent pool. The new weir is not expected to change the current hydraulic situation significantly and should not drive a substantial increase in sediment transfer to the downstream reach.

### 7.5.2 Reinstatement of flow through the outfall

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. The transport of most grain sizes in the outfall reach is likely to only occur during high flow events, during which discharges from the outfall structure will be insignificant compared to flows in the Celynog. However finer sediment is likely to accumulate at the abutments of the arch road bridge downstream (structure 6). Potential options to limit the potential for erosion and scour of this finer material is to discharge water onto a water bedrock cascade or use baffles in the outfall channel to reduce flow velocities from the outfall structure. The discharge outfall structure should also be placed as parallel to the channel banks as possible to limit the potential for erosion of the banks also.

### 7.5.3 Abstraction/Reduced flow within the flow depleted reach

A proportion of the flow from the Afon Celynog will be routed into the intake and pipeline through to the turbine before rejoining the channel approximately 370 m downstream. This will in turn reduce the available flow within the Afon Celynog forming a flow depleted reach.

Currently it is proposed that the scheme will abstract water all year round at an instantaneous rate not exceeding 369 l/s.

The Hands of Flow (HOF) has been agreed as 41 l/s. 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 has been agreed as a percentage of 40% taken above the HOF, with 60% remaining within the reach. This ratio is to be maintained by an open rectangular notch within the weir.

Aforementioned, low flow conditions are of fundamental importance to the ecological status of the watercourse, therefore it is important the implications of reduced flow regime on the 370 m 'flow depleted' reach is appropriately assessed. Given the baseline understanding of the reach downstream of the intake and weir, with its steep, cascade and 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 and other bryophytes) 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 scheme.

## **8 Conclusions**

The conclusions and recommendations from this study are as follows:

- Sediment transport calculations supported by observations from the geomorphological survey of the reach indicate that sediment transport is limited along the Afon Celynog.
- Some sediment transport may occur for finer gravel sediment and small to medium sized pebbles, but this will be limited to high flow events.
- A total of six structures/modifications were identified along the Afon Celynog. Of these, only the two weir structures are likely to be significant barriers to sediment transfer, acting to temporarily store finer sediment between high flow events.
- In terms of scheme B the intake weir will act to impound flows upstream. This has the potential to cause a fall in flow velocity upstream and an increase in flow velocities immediately downstream. As the structure is proposed to utilise a natural step and pool sequence where there will already be a natural slowing of flow velocities followed by a subsequent increase in velocity, the scheme's potential impact on existing velocities in the reach is somewhat reduced.
- A second characteristic of the weir is that it will form a barrier of uniform height across the river section, which could inhibit bedload transport downstream. A potential option to reduce this impact is to backfill the area immediately behind the weir with retained gravel up to the level of the weir crest, ensuring that sediment transfer processes are maintained as much as possible.
- In terms of scheme C the intake weir will be replacing a long established Ogee weir, therefore it is unlikely to lead to a significant change in the current functioning of the reach. The proposals will ensure that the water level upstream remains the same and there should be little change in the existing pool upstream.
- The outfall structures for both schemes are to be located upstream of existing arch bridges where finer sediment may accumulate. Potential options to limit the potential for erosion and scour of this finer material is to discharge water onto a water bedrock cascade or use baffles in the outfall channel to reduce flow velocities from the outfall structure. The discharge outfall structures should also be placed as parallel to the channel banks as possible to limit the potential for erosion of banks also.
- With regard to abstraction, there is unlikely to be any significant detrimental impact on the seasonal flow regime as a result of both schemes, therefore it is not envisaged that the existing habitats will be affected.

Ultimately the potential for any significant impact on the Afon Celynog from the proposed works is considered to be negligible. The proposed works are unlikely to compound any existing issues in terms of sediment transport provided the recommended measures are applied and the scheme should not cause a risk of deterioration in terms of the existing water body WFD status.

**Appendix 1 – Plans**

## **Appendix 2 – Field Notes & Photographs**

**Appendix 3 – Bankfull Area Calculations**

**Appendix 4 – Structures**