Glen Earrach

Response to Request for Further Information Regarding the Effects of Changes to the Flow Regime in the River Ness on migrating Atlantic Salmon

Electricity Act 1989
Town and Country Planning (Scotland) Act 1997
The Electricity Works (Environmental Impact Assessment) (Scotland) Regulations 2017

Glen Earrach Energy Pumped Storage Hydro (PSH) Project
ECU Ref: ECU00005121

This document has been prepared by WestGlen Consult Ltd. on behalf of the Applicant, in response to the request for further information (item c) by NatureScot in their letter with reference CDM173569 dated 19 January 2026.

Executive Summary

In response to the further information requested by NatureScot, the Applicant has undertaken an assessment of potential effects on Atlantic Salmon under the predicted changes to the flow regime in River Ness, arising from operation of Glen Earrach Pumped Storage Hydro (PSH) (the Proposed Development). This applies to winter only (1st October to 31st April) since during the summer (1st May to 30th September), the Seasonal Variable Weir eliminates impacts on River Ness. As referenced by NatureScot, the approach set out in Bakken (2023) can be usefully applied to evaluate the potential effects on Atlantic Salmon. To support application of this framework, the Applicant has held a discussion with Atle Harby (Sintef), a co-author of the Bakken (2023) paper and the lead of the study underlying the paper, to confirm interpretation of the methodology and key assessment parameters and how these should be applied to PSH activity in the context of discharge to a large lower reservoir such as Loch Ness.

It is noted from this discussion, Bakken (2023) and Alfredsen (2022) (also cited by NatureScot) that stranding is the primary concern associated with hydropeaking. Accordingly, of the six hydromorphological effect factors considered in the framework, the rate of change in dewatered level (E1) and the change in dewatered area (E2) are considered the most important parameters. Atle Harby clarified that parameter E1 of less than 5cm/h may be used as a threshold for “no hydropeaking”. A further benchmark value of 13 cm/h for the same parameter is also referenced as a guideline limit in Alfredsen (2022).

Based on these references, the Applicant undertook the assessment as set out in Annex 1.

In line with a precautionary approach, the assessment has been undertaken without taking account of the beneficial attenuation effects on rates of change in downstream river flow which a large body of water such as Loch Ness provides. This beneficial impact is likely to be non-negligible and will improve the results presented in this assessment.

Table 1 provides the results from the assessment carried out in line with the above methodology. The results demonstrate that operation of the Proposed Development, taking into account the combined influence of Loch na Cathrach and Loch Kemp PSH operations as well as the existing Foyers PSH, falls within the **Small (Green)** category under the total impact assessment, with a **moderate hydropeaking effect** and **low vulnerability**. Table 2

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and Table 3 present the calculated values for each parameter assessed under the above methodology. **The E1 rate of change parameter is calculated at 10cm/h, less than the guideline limit of 13cm/h identified in Alfredsen (2022).** For completeness, increasing flow rate of change has also been calculated, with a rate of change of 11.38cm/h.

For comparison purposes, an assessment was also carried out of only Loch na Cathrach, Loch Kemp and Foyers PSH operations, without the influence of the Proposed Development. These results demonstrate the same result, with Small (Green) impact, made up of moderate hydropeaking effect and low vulnerability. Operation of Loch na Cathrach alone with Foyers shows an E1 value of less than 5cm/h, which is considered as no hydropeaking, as noted above. This is also the case for the current baseline (with Foyers PSH operations only).

For completeness only, an assessment has been carried out of partial variable weir operation in the winter. This assessment concludes that with only 55% operation of the weir, an E1 value of less than 5cm/h is achieved eliminating hydropeaking effects entirely. For the avoidance of doubt, this is not required as mitigation of the scheme since the previous assessment concludes no negative hydropeaking impact even with no operation of the weir.

Table 1 - Final results for total impact assessment (combination of hydromorphological effect and vulnerability assessment)

		Hydropeaking Effect[a]			
		Small	Moderate	Large	Very Large
Vulnerability[b]	Low		X		
	Moderate				
	High				

[a] *"Small" – range 4 to 9, "Moderate" – range 10 to 14, "Large" – range 15 to 20, "Very large" – range 21 to 32*

[b] *"Low" – equal to or lower than 10, "Moderate" – between 10 and 16, "High" – greater than 16*

Parameter calculations and plots

Table 2 - Results for hydromorphological assessment

Hydromorphological Effect Factor	Value	Score
E1: Rate of change	10.06 cm/h	2 (Moderate)
E2: Dewatered area	3.00%	1 (Small)
E3: Magnitude of flow changes	2.34	2 (Moderate)
E4: Frequency	> 40%	4 (Very large)
E5: Distribution	Daily regulation in several periods	2 (Moderate)
E6: Timing	In daylight in winter	4 (Very large)
Total Score		**14 (Moderate)**

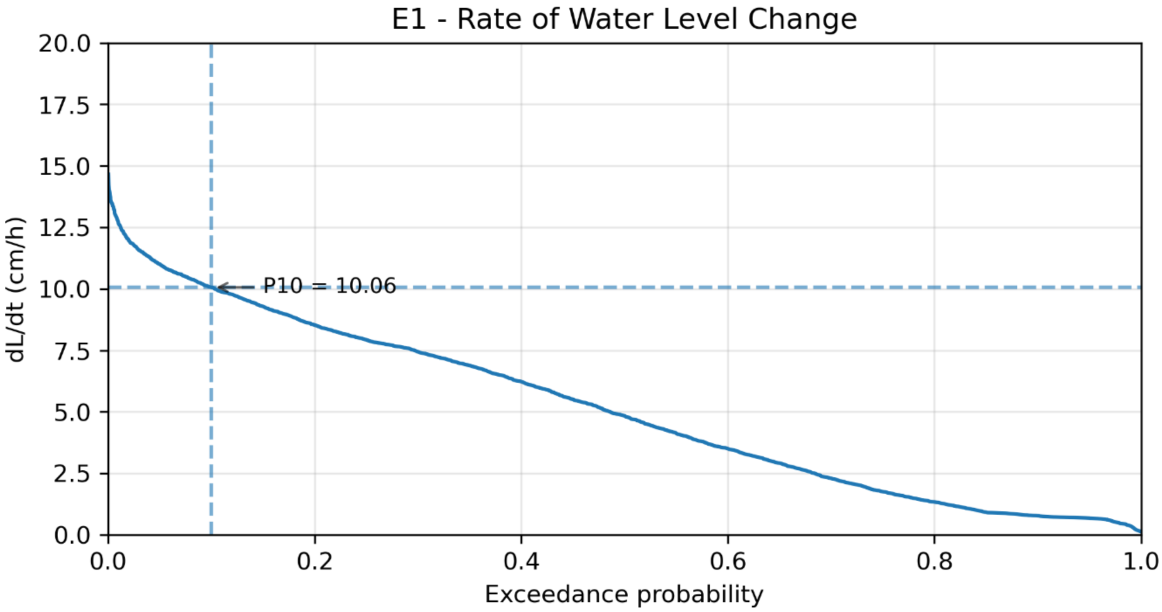
Table 3 - Results for vulnerability assessment

Vulnerability Factor	Value	Score
V1: Effective population size (Ne)	379 females	1 (Low)
V2: Degree of limitations in recruitment	Moderate	2 (Moderate)
V3: Low flow periods as bottleneck for fish stock size	1-30% (No or weak bottleneck)	1 (Low)
V4: Habitat degradation	Low probability	1 (Low)
V5: Reduced water temperatures that lead to population effects	Small (<1°C), small population effect	1 (Low)
V6: Other factors	No or small reduction in fish stock or carrying capacity	1 (Low)
V7: Percentage of impacted river length compared to total length	>40%	3 (High)
Total Score		**10 (Low)**

Hydromorphological Assessment

<u>E1: Rate of change</u>

Figure 1 - Rate of water level change exceedance curve

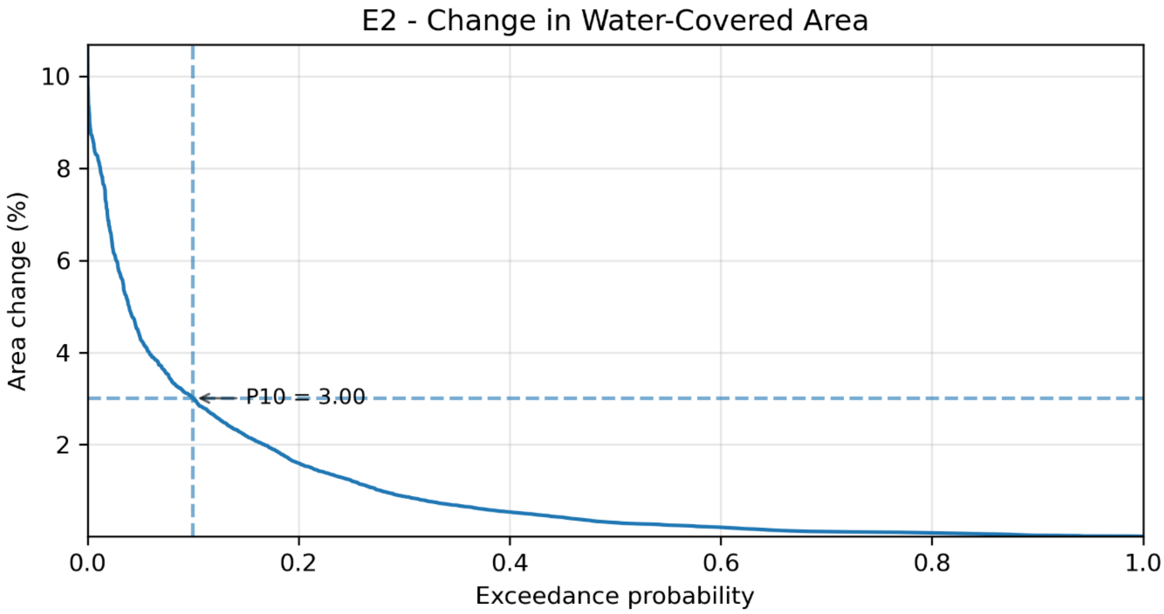


Note: P10 (10% exceedance) is equivalent to the 90th percentile

The 90th percentile of rate of water level change is 10.06 cm/h, as shown in Figure 1, corresponding to the "Moderate" category with a score of 2.

E2: Dewatered area

Figure 2 - Change in water-covered area exceedance curve



Note: P10 (10% exceedance) is equivalent to the 90th percentile

The 90th percentile of change in water-covered area is 3% as shown in Figure 2, corresponding to the "Small" category with a score of 1. The derivation of water-covered area is provided in Annex 2.

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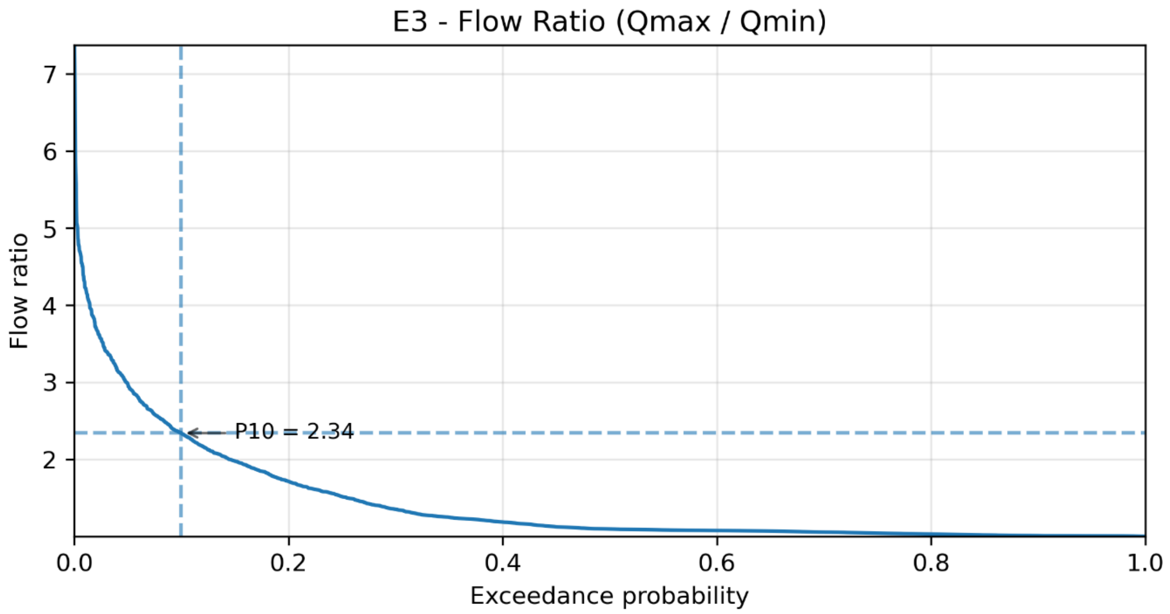
E3: Magnitude of flow changes

Figure 3 - Flow ratio exceedance curve



Note: P10 (10% exceedance) is equivalent to the 90th percentile

The 90th percentile of flow ratio is 2.34 as shown in Figure 3, corresponding to the "Moderate" category with a score of 2.

E4: Frequency

All PSH activities occur daily throughout the year (100% frequency). Therefore, it is classified as "Very large" category with a score of 4.

E5: Distribution

All PSH activities occur daily across all seasons. Therefore, it is classified into "Moderate" category with a score of 2, reflecting daily regulation in several periods, where the periods refer to seasons.

E6: Timing

All PSH activities largely follow market price signals, with pumping typically occurring at night and generation during the day. Flow reductions associated with pumping start-up or generation shut-down are therefore most likely to occur in darkness (considering winter hours). With the likelihood being flow reductions occurring in darkness in winter, this would correspond to a score of 3. However, accepting that there may be changes in market conditions and taking a precautionary approach, this parameter has been assigned a score of 4, representing a worst case corresponding to flow reductions in daylight in winter.

Vulnerability Assessment

The following parameters were assessed and reviewed by AECOM on behalf of the Applicant, unless otherwise specified.

<u>V1: Effective population size (Ne)</u>

Rod-catch data for Atlantic salmon (*Salmo salar*) and grilse (one-sea-winter; 1SW salmon) from 1952 to 2024 are available for the Ness catchment (NDSFB, 2024) and are summarised in Figure 1(note that NDSFB has not yet published results for 2025). Following the approach used by Bakken *et al.* (2023), estimates of the average number of females were calculated for the most recent five years of records by applying a 56.8% female sex ratio. This sex ratio was derived from the Ness and Beauly Fisheries Trust Adult Salmon Scale Sampling Programme (N&BFT, 2019). The resulting estimates are presented in Table 2**.**

Figure 4 - Reported rod catches of salmon and grilse from the NDSFB Annual Report 2024 (NDSFB, 2024).

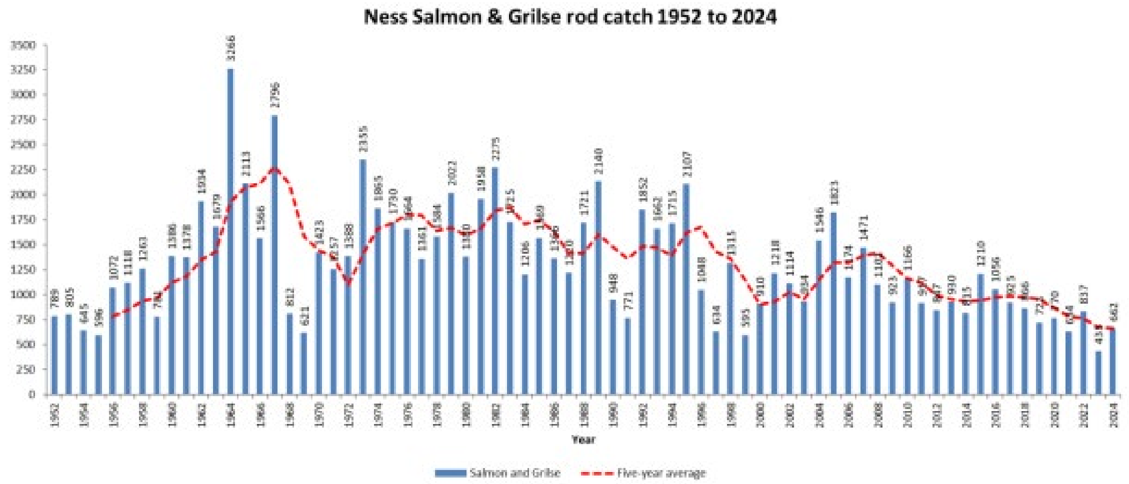


Table 4 - Estimated female component (based on rod catch; with colour coding based on the Bakken et al. (2023) assessment criteria, whereby green = Low (value 1), yellow = Moderate (value 2))

	2020	2021	2022	2023	2024	Total
Salmon and Grilse	770	634	837	435	662	3338
56.8% female sex ratio	437	360	475	247	376	1896

Given that rod-catch data underestimates total population size, owing primarily to varying fishing effort and gear selectivity, the actual number of female salmon in the population is almost certainly higher than these estimates (NDSFB, 2024). That said, using the calculated numbers of female salmon (which represents a worst case following the precautionary approach), the annual totals in all but one year (2023), exceed the required cumulative five-year total as outlined by Bakken *et al.* (2023). Across the five-year period, the combined number of individuals is 3,338.

As the combined five-year threshold is exceeded and acknowledging the under-representation inherent in rod-catch data, it is recommended that **V1 is assessed as Low (value 1) with a high confidence rating**.

Please note that these numbers represent the entire catchment rather than solely the study area. Although population scale is not explicitly defined in Forseth and Harby (2014), assessing *Ne* at the whole-catchment level is considered most appropriate, as distinguishing salmon spawning in the River Ness from those merely migrating through would be extremely difficult.

V2: Degree of limitations in recruitment

Forseth and Harby (2014) state that assessing V2 requires detailed habitat mapping of both spawning habitat and juvenile shelter (see p. 22, Tables 1–4). At present, such fine-resolution habitat data are not available for the River Ness, meaning that any assessment will necessarily carry a low level of confidence. The two realistic options are therefore to:

i. commission habitat surveys, or

ii. adopt a precautionary approach based on existing desk-based information

Of the available desk-based information, the most informative dataset is provided in the cbec eco-engineering (2023) report, which presents mapped substrate and hydrological characteristics for the River Ness across three reaches. However, these maps do not include definitions of sediment size classes, hydrological unit criteria, or measurements of water depth and velocity; parameters needed to accurately classify spawning and juvenile shelter habitats in line with Forseth and Harby (2014).

If applying a precautionary approach, and assuming that substrate classified as gravel to cobble, and hydrological units classified as run to glide, represent potentially suitable spawning habitat, then the cbec mapping suggests that approximately 30% of the River Ness channel comprises habitat that could be considered suitable for spawning, with a moderate distribution.

Information on juvenile shelter is more limited and would ideally require targeted field surveys to quantify accurately. However, notes throughout the N&BFT habitat survey (N&BFT, n.d.) and the NDSFB fish population survey report (2023) indicate that although suitable juvenile habitat exists within the main stem, bankside shelter is locally limited. This appears to be particularly associated with historic river modification, including the Caledonian Canal, bank reinforcement, and hydropower-related engineering.

Given the moderate distribution of potential spawning habitat and the possible constraints on juvenile shelter, and applying the precautionary principle in the absence of higher-resolution data, it is recommended that **V2 is assessed as Moderate (value 2) with a low confidence rating**. Commissioning dedicated habitat surveys would substantially increase confidence in this assessment and should be considered a priority if a higher-resolution evaluation is required.

V3: Low flow periods as bottleneck for fish stock size (calculation by WestGlen, results assessed by AECOM)

Table 5 - Percentage Change in Lowest Annual Weekly Flow in Winter (2016 - 2023). "GE + LnC + LK" refers to the cumulative operation of PSH.

Year	Baseline, Qmin (m3/s)	GE + LnC + LK, Qmin (m3/s)	Reduction %
2016	47.33	42.85	9.46
2017	45.77	32.62	28.72
2018	41.01	35.70	12.94
2019	37.46	33.20	11.38
2020	46.38	45.91	1.01
2021	42.48	36.25	14.67
2022	39.96	40.68	-1.79
2023	43.21	41.41	4.17

As shown in Table 3, the reduction in the lowest average weekly flow from unregulated to regulated state ranges from 1% to 28.7%, which fall within No or weak bottleneck category under the classification from Forseth and Harby (2014), **corresponding to Low (value 1)** score in Bakken (2023)**.** A positive effect is observed only in 2022 (a 1.8% increase); however, this is excluded from the assessment following a precautionary approach.

V4: Habitat degradation

The following commitment was made by the Applicant to SEPA as part of the technical clarification provided by the Applicant to SEPA in October 2025:

"*…no negative impact to flood receptors (either around Loch Ness or downstream in River Ness) either by way of magnitude or frequency of flood events compared to a baseline of the current behaviour of the Loch Ness catchment and taking account of existing CAR licenses, and considering a range of flood events up to and including a 1 in 200 + climate change event.*"

In accordance with this commitment, neither the frequency nor magnitudes of flood events on River Ness will be changed, and hence no habitat degradation induced by the change in flood event. Therefore, it is assessed with a score of **Low (value 1)**.

V5: Reduced water temperatures that lead to population effects

There is no evidence of temperature impacts on the River Ness within the EIAR, as any effects are expected to be localised to Loch Ness. The overall temperature-related impact is assessed as low because the regular energy-generation cycles reduce the standing time in the headpond, limiting the potential for temperature change. Additionally, any temperature variation would be minor and buffered by Loch Ness before water enters the River Ness. Therefore, it is concluded with a score of **Low (value 1)**, smaller than 1°C.

V6: Other factors

There is no evidence of additional relevant impacts within the EIAR. Therefore, it is concluded with a score of **Low (Value 1)**, no or small reduction in fish stock or carrying capacity.

V7: Percentage of impacted river length compared to total length

It is expected that the entirety of the River Ness is affected by generation and pumping cycles. Therefore, it is concluded with a score of **High (Value 3)**.

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Reference list

1. Alfredsen, Knut & Juárez-Goméz, Ana & Kenawi, Mahmoud & Graf, Magnus & Saha, Sanjoy. (2022). Mitigation of environmental effects of frequent flow ramping scenarios in a regulated river. Frontiers in Environmental Science. 10. 944033. 10.3389/fenvs.2022.944033.

2. Bakken, T. H., Harby, A., Forseth, T., Ugedal, O., Sauterleute, J. F., Halleraker, J. H., & Alfredsen, K. (2023). *Classification of hydropeaking impacts on Atlantic salmon populations in regulated rivers*. River Research and Applications, 39(3), 313–325. https://doi.org/10.1002/rra.3917

3. cbec eco-engineering (2023). *River Ness Habitat Improvement Feasibility Study: Final report*. Inverness: cbec eco-engineering UK Ltd for the Ness District Salmon Fishery Board. Project ref. 21-1022, final issue dated 24 February 2023.

4. Forseth, T. & Harby, A. (2014). *Handbook for Environmental Design in Regulated Salmon Rivers*. Norwegian Institute for Nature Research (NINA), Trondheim.

5. N&BFT (Ness & Beauly Fisheries Trust) (2019). *Adult Salmon Scale Sampling Programme: Review of 2015–2018 data*. Inverness: NBFT.

6. N&BFT (Ness & Beauly Fisheries Trust) (n.d.). *Ness System Habitat Survey*. Inverness: Ness & Beauly Fisheries Trust.

7. NDSFB (Ness District Salmon Fishery Board) (2023) *Fish population surveys of the Ness Catchment 2023*. Inverness: NDSFB.

8. NDSFB (Ness District Salmon Fishery Board) (2024). *NDSFB Annual Report 2024*. Inverness: NDSFB.

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ANNEX 1

Hydromorphological Assessment Methodology

Overview

The document outlines methodology used to assess hydromorphological alteration on the River Ness under Glen Earrach Pumped Storage Hydropower (PSH) operation (referred to hereon in as the Proposed Development), including considering cumulative impacts associated with other existing and proposed pumped storage projects on Loch Ness (namely Foyers PSH, Loch Kemp PSH; and Loch na Cathrach PSH). The assessment follows the classification framework proposed by Bakken (2023)[1], as referenced by NatureScot in its letter reference CDM173569 dated 19 January 2026. The framework provides context for how conventional hydropower operation leads to changes in river flow and associated environmental effects, particularly on Atlantic Salmon.

Where certain aspects of the parameter descriptions in the Bakken (2023) classification framework are not fully defined, reference has been made to the earlier original Norwegian study[2], which was the basis of the 2023 paper, to support interpretation. The methodology presented in this document follows Bakken (2023) as the primary reference. Supplementary information from other references is applied only where explicitly stated.

Data

The assessment was based on River Ness flow and depth time-series data and pumped-storage hydro operation time-series data generated by the Applicant's hydrological and operational model as presented in the original EIAR (March 2025) and subsequently as part of provided Additional Information in June 2025 and August 2025. All datasets were available at half-hourly temporal resolution and covered the period from 2016 to 2024 corresponding to the available production data in line with the description in Chapter 11 of the EIAR.

[1] Bakken, Tor & Harby, Atle & Forseth, Torbjørn & Ugedal, Ola & Sauterleute, Julian & Halleraker, J. & Alfredsen, Knut. (2023). Classification of hydropeaking impacts on Atlantic salmon populations in regulated rivers. River Research and Applications. 39(3), 313–325.

[2] Bakken, Tor & Forseth, Torbjørn & Harby, Atle & Alfredsen, Knut & Arnekleiv, Jo & Berg, Ole Kristian & Casas-Mulet, Roser & Charmasson, Julie & Greimel, Franz & Halley, Duncan & Hedger, Richard & Larsen, Bjørn & Leo, Florian & Melcher, A. & Puffer, Michael & Pulg, Ulrich & Reitan, Ole & Rüther, Nils & Saltveit, S. & Zinke, Peggy. (2016). Miljøvirkninger av effektkjøring: Kunnskapsstatus og råd til forvaltning og

Table 1 - Hydromorphological Effect Factors and Class Borders (Bakken, 2023)[3]

Effect factors	Indicator	Unit	Criteria for hydromorphological assessment			
			Small (value 1)	Moderate (value 2)	Large (value 3)	Very large (value 4)
E1: Rate of change	Water level change ratio	cm/h	<5	5–13	13–20	>20
E2: Dewatered area	Change in water-covered areas when flow is reduced from Qmax to Qmin	%	<5	5–10	10–20	>20
E3: Magnitude of flow changes	Flow ratio Qmax/Qmin	Ratio	<1.5	1.5–3	3–5	>5
E4: Frequency	Annual frequency—proportion of days per year	% (no of days)	<10 (<37)	10–25 (37–91)	25–40 (92–146)	>40 (>146)
E5: Distribution	Distribution of the hydropeaking throughout the year	Qualitative	Daily regulation in maximum two period	Daily regulation in several periods	Irregular in certain periods	Irregular throughout the year
E6: Timing	Flow reductions in critical periods	Qualitative	Spring and early summer	Summer and fall	In darkness in winter	In daylight in winter

Event Definition

Key framework parameters are associated with each drawdown event resulting from operational activities. The following event definitions apply to all parameter calculations described below:

- An event in accordance with the methodology set out in Bakken (2023) represents a water-level drawdown resulting from PSH operations[4];
- An event is defined as starting when the water level begins to fall and is considered complete when 90% of the total water level-reduction has occurred[5]; and
- Taking reference from the COSH tool framework adopted in Bakken (2023), the calculation of event-based parameters first requires the identification of peaking events[6]. To do so, pumped-storage activity from the underlying production data is used as a trigger to distinguish operation-induced artificial drawdown events from natural fluctuations (i.e. an artificial drawdown is identified when pumping starts or when turbine generation is turned off).

The above methodology for identification of relevant events allows the production of a full event time series for subsequent analysis of each of the Parameters described below.

[3] Bakken, Tor & Harby, Atle & Forseth, Torbjørn & Ugedal, Ola & Sauterleute, Julian & Halleraker, J. & Alfredsen, Knut. (2023). Classification of hydropeaking impacts on Atlantic salmon populations in regulated rivers. River Research and Applications. 39(3), 313–325.
[4] p. 155, *Miljøvirkninger av effektkjøring: Kunnskapsstatus og råd til forvaltning og*, Bakken et al., 2016.
[5] p. 155, *Miljøvirkninger av effektkjøring: Kunnskapsstatus og råd til forvaltning og*, Bakken et al., 2016.
[6] Sauterleute, J. F., & Charmasson, J. (2014). A computational tool for the characterisation of rapid fluctuations in flow and stage in rivers caused by hydropeaking. *Environmental Modelling & Software*, *55*, 266–278. https://doi.org/10.1016/j.envsoft.2014.02.004

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Parameter Calculation

E1: Rate of change in water level

- Defined as the rate of water level change between the start and end of a drawdown event (cm/h).
- The 90th percentile[7] of all events over the full event time series is used as the representative metric for comparison against classification thresholds.

E2: Dewatered area

- Defined as the change in wetted area between conditions before drawdown event at Qmax and after drawdown completion at Qmin, expressed as percentage of the wetted area at Qmax.
- Wetted area corresponding to level gauge data is derived from satellite imagery and used to establish a level-area relationship through interpolation of the available data points (see Annex 2).
- River levels at Qmax and Qmin are then converted to wetted area using this relationship to quantify the change in wetted area.
- For this assessment, the 90th percentile is adopted as the representative metric consistent with the approach associated with other parameters.

E3: Magnitude of flow changes

- The ratio between flow before drawdown (Qmax) and flow after drawdown (Qmin)[8].
- The 90th percentile[9] of all events over the full event time series is used as the representative metric for comparison against classification thresholds.

E4: Frequency

- The number of days per year during which events occur.

E5: Temporal distribution

- Qualitative assessment based on operational profile. The reference to Periods within the parameter definition means annual seasons[10]. The number of seasons during which PSH activity takes place, and whether that activity is daily or irregular, is the basis of the assessment.

E6: Timing

- Qualitative assessment based on operational profile. Assessing the timing of when PSH activity takes place.

[7] p. 155, *Miljøvirkninger av effektkjøring: Kunnskapsstatus og råd til forvaltning og*, Bakken et al., 2016.
[8] p. 156, *Miljøvirkninger av effektkjøring: Kunnskapsstatus og råd til forvaltning og*, Bakken et al., 2016.
[9] p. 156, *Miljøvirkninger av effektkjøring: Kunnskapsstatus og råd til forvaltning og*, Bakken et al., 2016.
[10] p. 157, *Miljøvirkninger av effektkjøring: Kunnskapsstatus og råd til forvaltning og*, Bakken et al., 2016.

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Vulnerability Assessment

Table 2 - Vulnerability Factors and Class Borders (Bakken, 2023)[11]

Vulnerability factor	Indicator	Criteria for vulnerability characterization		
		Low (value 1)	Moderate (value 2)	High (value 3)
V1: Effective population size (N_e)	Average no. of females last 5 years	>250 females	25–250 females	<25 females
V2: Degree of limitations in recruitment	Amount and spatial distribution of spawning grounds	Much and evenly distributed	Moderate	Low and patchy distributed
V3: Low flow periods as bottleneck for fish stock size	Change in lowest annual weekly flow in winter and summer combined	No or weak bottleneck	Moderate bottleneck	Strong bottleneck
V4: Habitat degradation	Change in magnitude and frequency of flood event, probability of degradation	Low probability	Moderate probability	High probability or documented
V5: Reduced water temperatures that lead to population effects	Reduction in summer water temperature and probability of population effects	Small (< 1°C), small population effect	Moderate (1–3°C), including probable population effect	Large (> 3°C), including probable or documented population effect
V6: Other factors	Acidification, water quality, habitat degradation due to other factors than regulations, diseases, parasites, etc.	No or small reduction in fish stock or carrying capacity	Moderately reduced fish stock or carrying capacity	Strongly reduced fish stock or carrying capacity
V7: Percentage of impacted river length compared to total length	Proportion of river reach with peaking compared to total anadromous length [%]	<10%	10–40%	>40%

The majority of the Vulnerability Assessment is a qualitative assessment carried out by fish ecologists.

Parameters V3 and V4 below requires a hydrological assessment.

V3: Low flow periods as bottleneck

- The percentage change in lowest annual weekly average[12] flow from unregulated to regulated conditions in summer and winter. This involves a direct comparison of the baseline with the PSH data series, comparing lowest annual weekly average flow for each case.

V4: Habitat degradation.

- Involves a first assessment of any changes in magnitude or frequency of flood events, following which an assessment of any such change on habitat degradation can be made.

[11] Bakken, Tor & Harby, Atle & Forseth, Torbjørn & Ugedal, Ola & Sauterleute, Julian & Halleraker, J. & Alfredsen, Knut. (2023). Classification of hydropeaking impacts on Atlantic salmon populations in regulated rivers. River Research and Applications. 39(3), 313–325.

[12] p. 25, *Handbook for environmental design in regulated salmon rivers*, NINA Special Report. 53, Forseth & Harby, 2014.

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ANNEX 2

River Ness Wetted Area Calculation Methodology

Methodology for E2 Parameter Assessment

1. Purpose

This note sets out the methodology used to derive the relationship between river level and total wetted area for the River Ness, from Dochfour Weir to the river mouth. This relationship is required for calculation of the E2 (dewatered area) parameter in the Bakken et al. (2023) hydropeaking classification framework.

2. Data Source

Wetted area data was derived from satellite imagery using the historical imagery function in Google Earth Pro.

3. Methodology

3.1 Identification of Available Imagery

The first step was to identify dates where complete, consistent satellite imagery was available for the entire River Ness from the downstream end of Dochfour Weir to the river mouth.

Using the time slider in Google Earth Pro, each available imagery date was checked by panning along the full length of the river while monitoring the imagery date displayed at the bottom of the screen. If the date remained consistent from one end of the river to the other, this confirmed a complete image set for that date. Dates where the imagery was only partial coverage were excluded.

This process identified 15 dates with complete imagery coverage, ranging from June 2016 to May 2025.

3.2 Linking Imagery to River Level

For each imagery date, the corresponding river level was obtained from publicly available SEPA data for the Ness-side gauging station. The daily average river level for each imagery date was recorded.

For two dates (February 2021 and April 2021), Ness-side gauge data was unavailable. For February 2021, the Foyers gauge level (16.236 mAOD) was used to estimate the river level via the established Foyers-to-Ness-side relationship. At higher loch levels, this relationship is well-defined, giving an estimated river level of 2.03 m on the local gauge (8.89 mAOD) with confidence of approximately ±11.5 cm.

The April 2021 date was excluded because the low loch level (Foyers gauge 15.713 mAOD) falls within the range where SSE sluice gate operation introduces significant uncertainty in the Foyers-to-Ness-side relationship.

3.3 Polygon Mapping

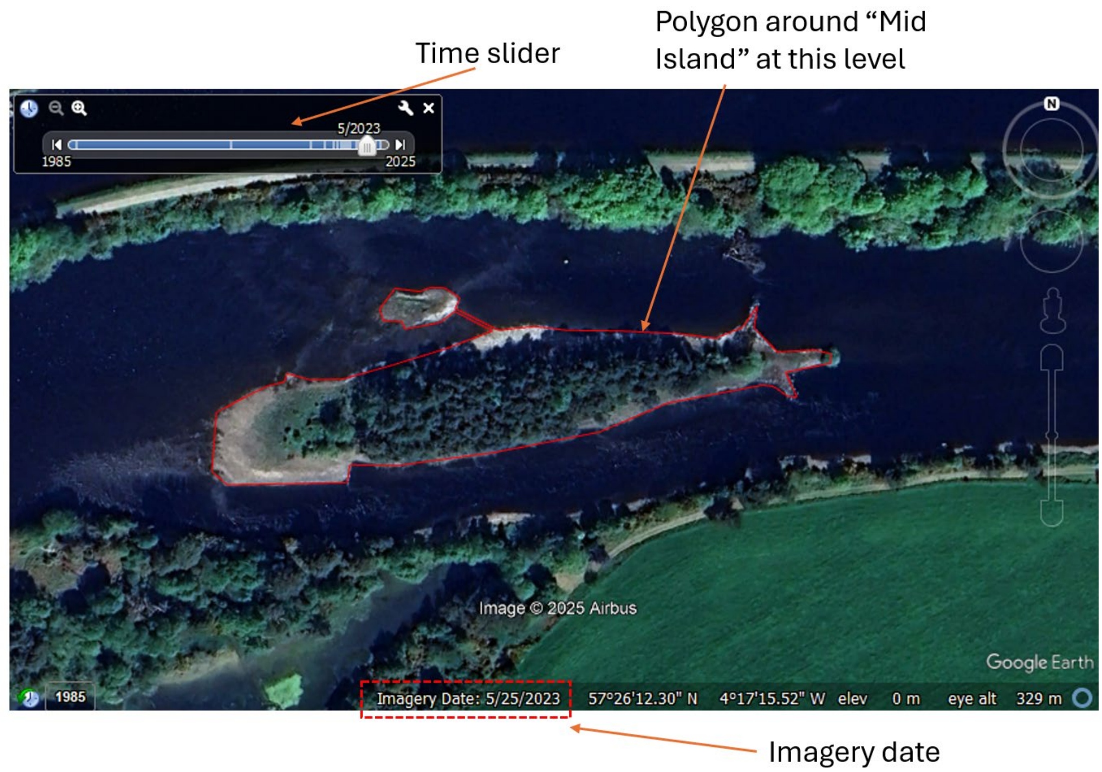

Figure 1 - Mid Island polygon in Google Earth Pro at 7.65 mAOD on 25/05/2023

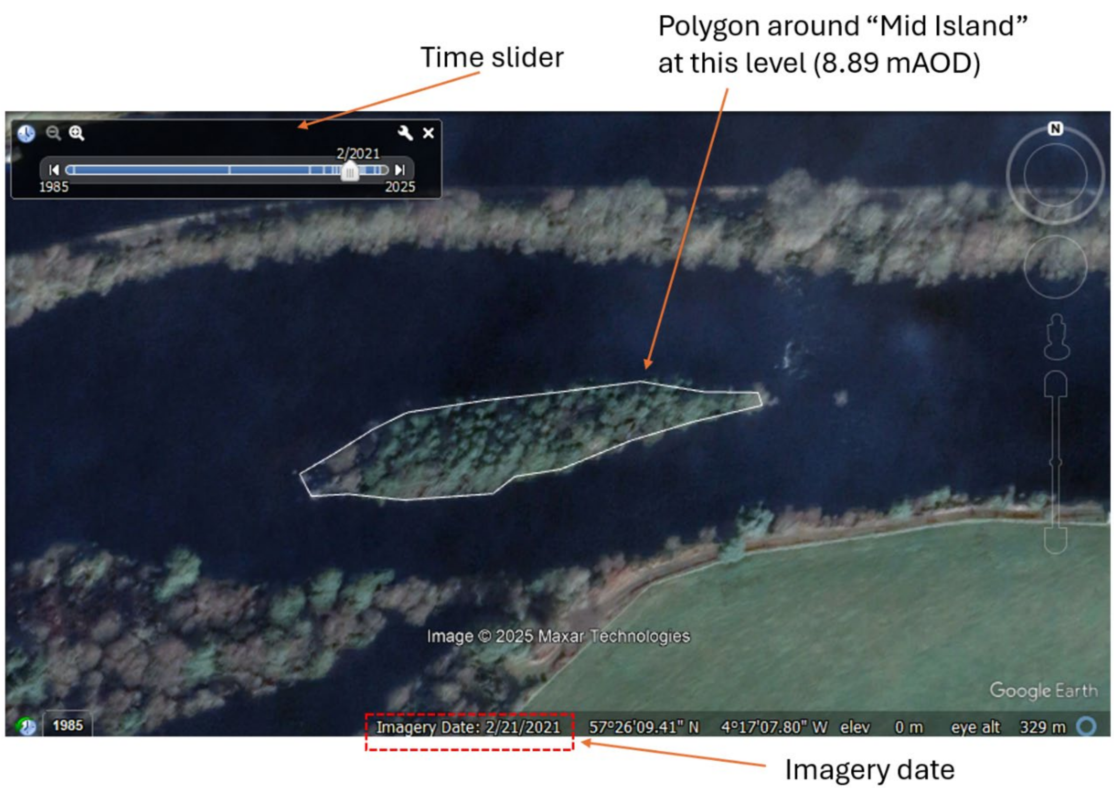

Figure 2 - Mid Island polygon in Google Earth Pro at 8.89 mAOD on 21/02/2021

For each selected imagery date, the wetted area was mapped using the polygon creation tool in Google Earth Pro. The mapping comprised:

1. **Outer river perimeter:** A polygon following the waterline of the outer river boundary, from the downstream end of Dochfour Weir to the river mouth. The polygon was drawn at high detail, carefully following the bank and mapping around features such as jetties, inlets, sandbars, exposed gravel areas, and any other features breaking the water surface.
2. **Ness Islands:** A polygon mapping the exposed land area of the Ness Islands group in central Inverness.
3. **Mid Island:** A polygon mapping the island located in the river between Inverness and the weir.
4. **Dochgarroch Island:** A polygon mapping the island adjacent to the first lock on the Caledonian Canal at Dochgarroch.

Each island polygon was remapped for each level, as island area varies with water level in the same way as the outer river boundary.

Two data points (7.60 and 7.77 mAOD) required small tidal adjustments to the polygon boundaries to account for tidal influence at the lower end of the river. At the highest river level (8.89 mAOD), a section of riverbank near the mouth was exposed due to low tide at the time of image capture. To ensure consistency, this tidally-exposed area was excluded from the wetted area calculation at all levels where it was visible.

3.4 Area Calculation

For each polygon, the area in square metres was obtained from Google Earth Pro via Properties > Measurements > Area.

Total wetted area was calculated as:

Total Wetted Area = Outer River Area − Ness Islands − Mid Island − Dochgarroch Island

4. Results

Six data points were derived, focusing on the lower and upper ends of the available level range:

Level (mAOD)	Date	Outer River (m^2)	Ness Islands (m^2)	Other Islands (m^2)	Total Wetted (m^2)
7.60*	07 Jan 2021	908,462	42,182	13,869	852,411
7.65	25 May 2023	922,381	40,767	12,878	868,736
7.71	14 May 2025	965,228	40,518	12,318	912,392
7.77*	29 Apr 2019	970,650	40,139	11,555	918,956
8.46	15 Oct 2019	982,824	38,876	7,993	935,955
8.89**	21 Feb 2021	1,003,747	35,423	7,337	960,987

** Small tidal adjustment applied. ** Level derived from Foyers gauge.*

5. Observations

The relationship between level and wetted area is monotonic and behaves as expected. Key observations:

1. There is a clear change in gradient (knee point) around 7.7–7.8 mAOD, corresponding to the point where gravel banks begin to emerge.
2. Below this level, wetted area decreases more steeply with falling level as shallow-sloping gravel features are progressively exposed.
3. Above 7.77 mAOD, the curve is close to linear up to the highest available level at 8.89 mAOD. In this range, most gravel banks are submerged and the river is more canalised, with level changes only affecting the steeper banks of both the islands and the river margins.
4. Island areas decrease with increasing level as expected, as lower-lying parts of the islands become inundated.

Below 7.77 mAOD, all available imagery has been used. Between 7.77 and 8.89 mAOD, additional images exist but would largely infill what is already a fairly linear section of the curve.

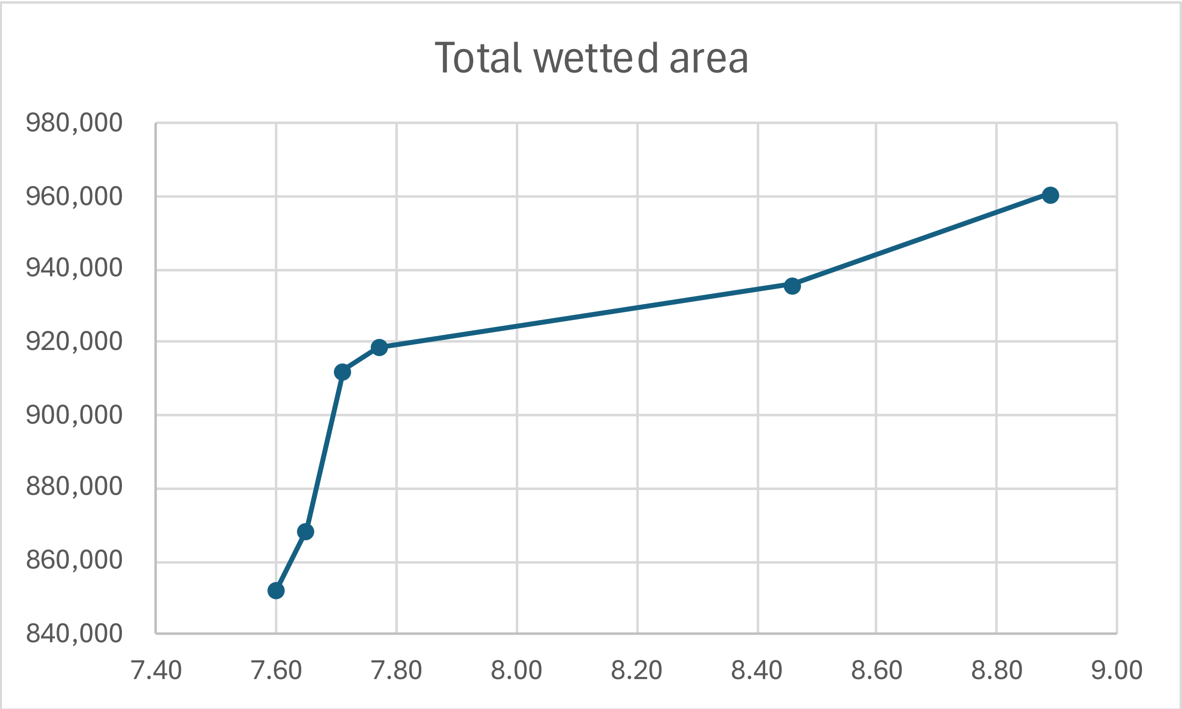

Figure 3 - Wetted Area vs Level (mAOD)