Balliemeanoch Pumped Storage Hydro

Environmental Impact Assessment Report

Volume 5: Appendices
Appendix 12.1: Water Resources Assessment

ILI (Borders PSH) Ltd

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Quality information

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Table of Contents

Figures

Tables

1 Introduction

1.1 Objectives

The objective of this report is to assess the following issues in relation to water resources:

- Major water resource demand within the Development proximity;
- Potential impact on water resources as a result of the Development; and
- Appropriate mitigation measures to reduce the impact of the Development on water resources.

1.2 Sources of data

To inform this study, information has been obtained from the following sources:

- SEPA Gauge data, for five rivers in the Loch Awe catchment, covering 48% of the catchment area,
- HadUK-Grid rainfall dataset, for rainfall estimates over Loch Awe,
- Hydro-PE HadUK-Grid dataset, for evapotranspiration, converted to evaporation values over Loch Awe using Environment Agency guidance1,
- Loch Awe level data provided by Drax,
- Loch Awe Barrage operating range targets, from the Cruachan 2 expansion application.

Date range for datasets (limiting date for modelling in bold)

Data	Start date	End date
Loch level	01/01/2013	31/12/2021
Loch level (hourly)	15/06/2019	14/06/2022
Gauged inflows	01/10/1981	30/09/2021
Rainfall (model)	01/01/1862	31/12/2022
Evaporation (model)	01/01/1969	31/12/2021

1.3 Development

The Development consists of a headpond impounded by two embankments. This is connected to Loch Awe (the tailpond) through underground tunnels and generating station. The Development's capacity assessed in this report is 1500MW. Full details of the Development are included in *Chapter 2: Project and Site Description (Volume 2: Main Report)*.

1.4 Basis of Assessment

The operational regime of the Development is governed by both water resource availability and the electricity market. This assessment considers the water resource impact of cyclical operation, as well as single abstraction or generation periods of varying durations as set out in *Section 3*.

[1] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/290579/sw6-043-hb-e-e.pdf

2 Loch Awe Baseline

2.1 Existing Water Resource regimes

Loch Awe is a freshwater loch with an area of 38.5 km^2. The outflow from the loch is down the River Awe, flowing into Loch Etive near Taynuilt. The River Awe is impounded by the Loch Awe Barrage, which generates electricity off the compensation flow at the Barrage and diverts water downstream to the Inverawe Power Station (25MW). Operations at the Loch Awe Barrage aim to maintain water levels within a seasonal range (see *Table 1*)[2]. The Barrage contains a Borland fish pass, a freshet gate and two radial gates for passing flood flows. The operation of these gates and the compensation flow system is variable and information on operations and corresponding outflows from Loch Awe were not available for this assessment.

Table 1. Target water levels

Period	Target minimum (mAOD)	Target maximum (mAOD)
April-November (Summer)	36.27	37.06
December-March (Winter)	35.96	36.57

The Cruachan pumped storage hydro scheme (440MW) abstracts water from Loch Awe, generally operating on a daily cycle. No data was available for the operation of the Cruachan pumped storage hydro scheme. A daily dataset of loch level measured at the Cruachan intake was available for 2013 to 2021. For the period of available loch level data the operation of the scheme is already reflected in the level duration curves. Analysis of loch levels between 2013 to 2021 shows that the winter operating range is exceeded approximately 25% of the time, while summer levels drop below the range approximately 30% of the time (see *Figure 2*).

Four small hydro schemes also operate using water from Loch Awe tributaries; Allt Beochlich, Allt Blarghour, River Avich and Loch Nant.

SEPA gauging stations cover approximately 50% of the Loch Awe catchment, as shown in *Figure 1 Location of gauges within the Loch Awe catchment*, below.

[2] These levels are given in the Cruachan 2 EIA report.

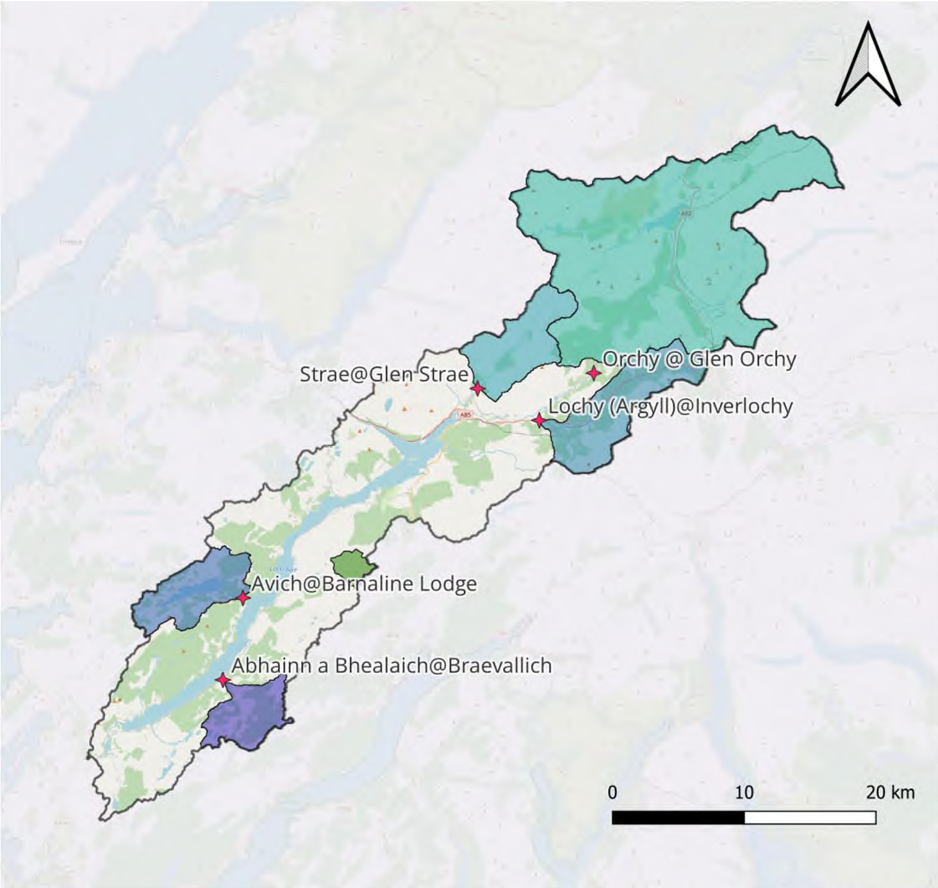


Figure 1: Location of gauges within the Loch Awe catchment.

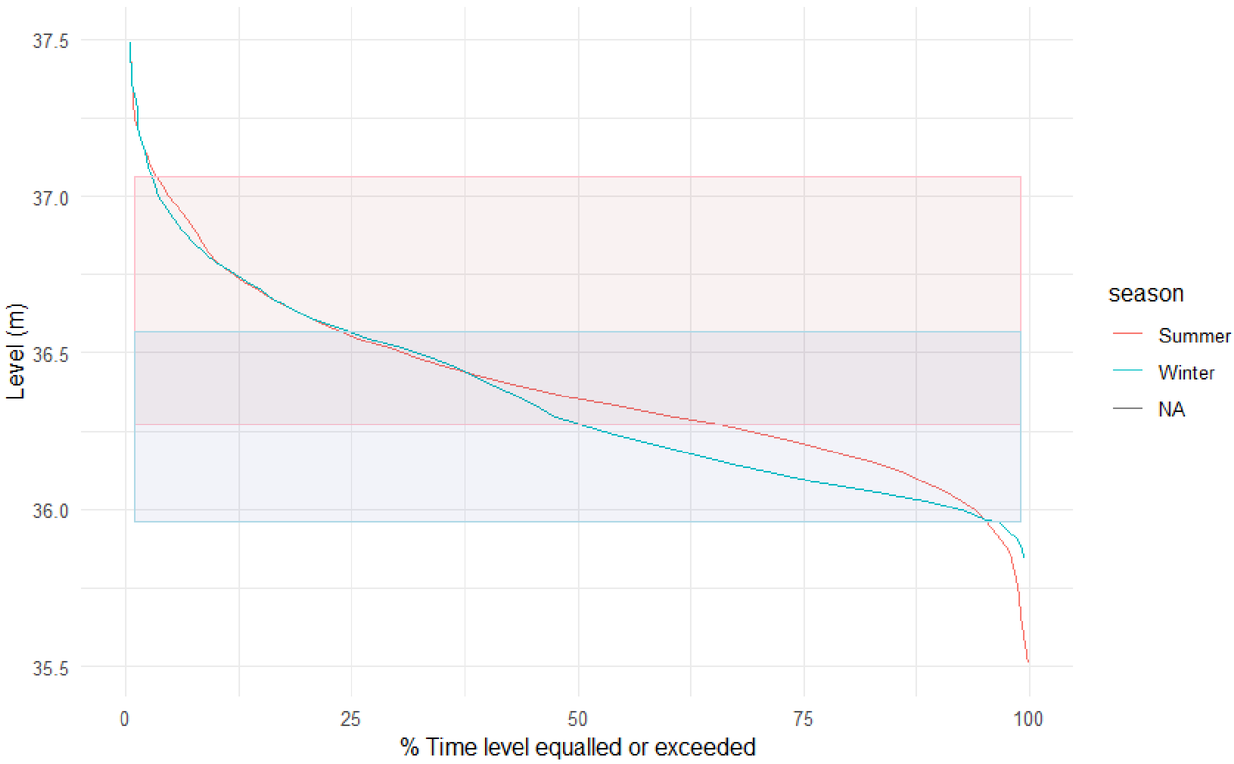


Figure 2: Water levels in Loch Awe (1/1/2013 - 31/12/2021)

3 Assessment Methodology

3.1 Water balance model setup

An understanding of the relationship between water level changes and outflows from Loch Awe is needed assess the impact of scheme operation on water resources. This relationship is determined by the operation of the Loch Awe Barrage. The barrage consists of three gates, a fish pass and two turbines. At the barrage water is abstracted to flow through pipes to Inverawe Power Station. The operation of these structures (opening or closing gates and abstracting water) determines the outflow from Loch Awe. Operation aims to keep water levels within specific ranges for the Summer (April-November) and Winter (December-March) periods. It is expected that during flood conditions, when the water level is high, the gates are opened fully. Because of these operating decisions, while higher loch levels generally correspond to higher outflow from the Loch, this is a statistical relationship rather than a definite relationship.

A water balance model was used to understand the statistical relationship between level and outflow by estimating the inflows to Loch Awe. This model provides a simplified understanding of the average outflow expected for a given water level.

Table 2: Water balance key terms

Change in Loch volume =	Inflows -	Outflows
	Gauged inflows	River Awe outflow and barrage abstraction
	Ungauged inflows	Evaporation
	Direct rainfall	

The water balance model was set up using data from the period 01/01/2013 to 30/09/2021. For ungauged inflows, flow was estimated by scaling the flow at the Orchy gauge based on catchment area. The model used a daily timestep. All variables are calculated as a daily volume. Outflow is then converted to m^3/s. Rearranging the water balance given in *Table 2* gives the following equation for Loch Awe outflows:

outflow = gauged inflows + ungauged inflows + direct rainfall - Δ storage – evaporation

3.2 Water balance model results

Outflow results generated through the water balance model are plotted against loch level in *Figure 3*. The results are plotted for each day over the model period, divided based on the operating season. Smoothed curves produced using a generalized additive model show the average relation between level and outflow. The scatter of points around the trend line reflects model uncertainties (regarding inflows), and the control of outflows by the operation of the Barrage.

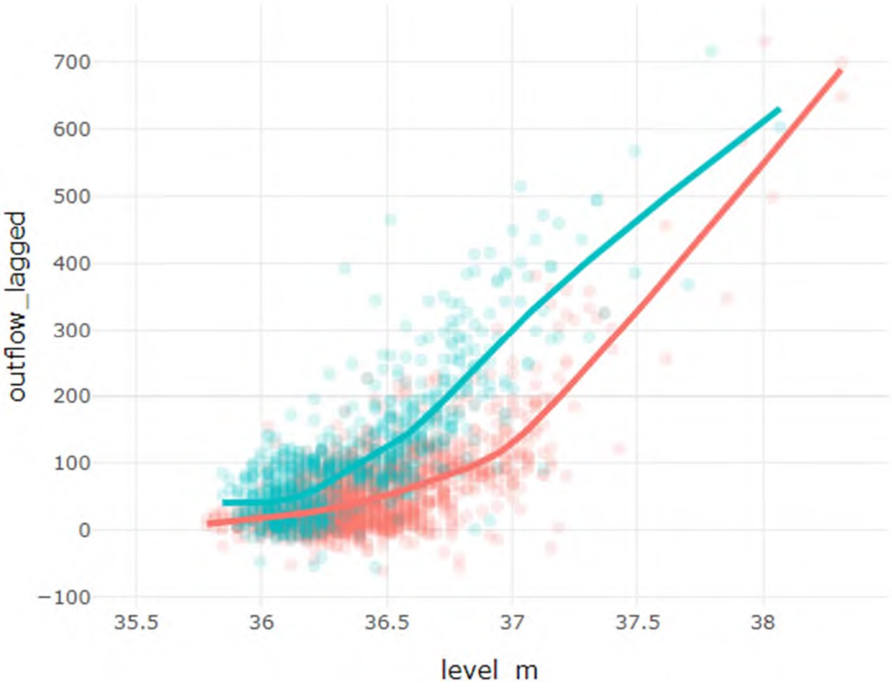
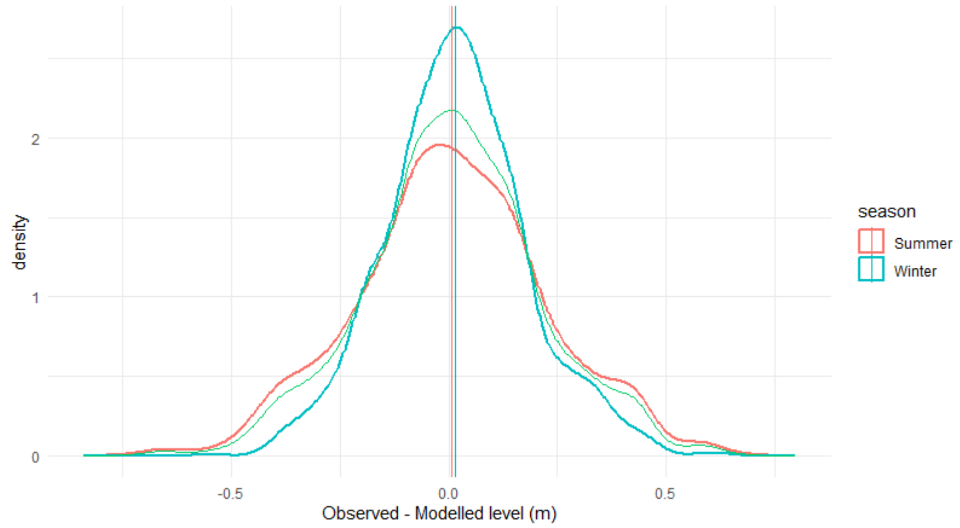


Figure 3: Loch level vs. outflow (summer in red, winter in blue)

3.3 Loch Awe ‘reservoir’ model setup

A Loch Awe reservoir model was built in Flood Modeller version 5.1. The Loch is modelled as a reservoir unit. It receives inflows from two flow units, representing the total streamflow and net direct rainfall (subtracting evaporation). The Development is represented as an abstraction unit. A flow-level boundary generates outflows from the Loch depending on the loch level – outflow relationship generated by the water balance model. The model is run separately for each season, as the level-outflow curves are different for the two seasons. Calibration of the model results against recorded loch levels indicated that the model was overestimating outflow at low loch levels during prolonged periods of low levels. To correct this, outflow values for the winter curve at 35.5m AOD and the summer curve at 36.0m AOD were reduced. The model assumed zero outflow below 35.5 mAOD.

Comparison of modelled and observed levels shows the average value for both seasons is within 2cm. The cumulative distribution of errors shows that approximately 75% of the model results are within +/- 0.25m of the observed levels. Sources of error for this model include: Cruachan operation, barrage operation significantly different from assumed curve, localised inflows (at north or south of catchment), not captured by the gauge interpolation approach for ungauged catchments and inaccuracy of flow gauges.



3.4 Modelled scenarios

Single operation

Table 3: Scenario matrix

Operating mode		Operating hours / % of capacity		Operating season (outflow curve)		Initial water level	Level exceedance probability over 2013-2021 daily record period
Abstraction (pumping) – 390m^3/s		30		Summer		35.97	95%
Generation – 480m^3/s	x	15	x	Winter	x	36.18	75%
		10				36.33	50%
		5				36.55	25%
						36.97	5%

To test the impact of the Development operation an assumed operation of either abstraction or generation was run. The runs of 5, 10, 15 and 30 hours represent between 15 and 100% of the capacity of the 1500MW scheme. The operation was added at the beginning of a 30-day model run. Model results were compared to the baseline with no abstraction or generation.

Model start times with an appropriate initial loch level were selected from the period of available data randomly. To account for different conditions during the following 30 days, 5 start times for summer and 5 for winter for each initial water level were selected. The scenario matrix is summarised in *Table 3*.

Cyclical operation

A second set of scenarios were run with a cyclical operation of the scheme. The first scenario was with abstracting water for 5 hours, then generating for 4.1 hours each day. These times equate to the same volume of water as the flow rate is higher for generation. The second scenario changed the order, beginning with generating. A set of initial starting conditions were chosen using the two operating seasons and 5 initial water levels from *Table 6*. The model was run for 30 days, using abstraction and generation rates of 390m3/s and 480m3/s respectively. These model runs assume that the operation of the Loch Awe Barrage does not adjust to the cyclical operation pattern.

4 Results

4.1 Rate of level change

The rate of change of the Loch level during pumping and generation was compared to the distribution of level changes from the hourly record of loch levels (2019-2021).

The rate of change during pumping is -3.4 cm/hr, while during generation the level rises at 4.2 cm/hr. These rates are close to the maximum observed for both increases and decreases in loch level, sitting above the 1% and 99% exceedance probabilities, as shown by the vertical lines on *Figure 3*. These rates of change are an input to the aquatic ecology assessment in *Chapter 7: Aquatic Ecology (Volume 2: Main Report)*.

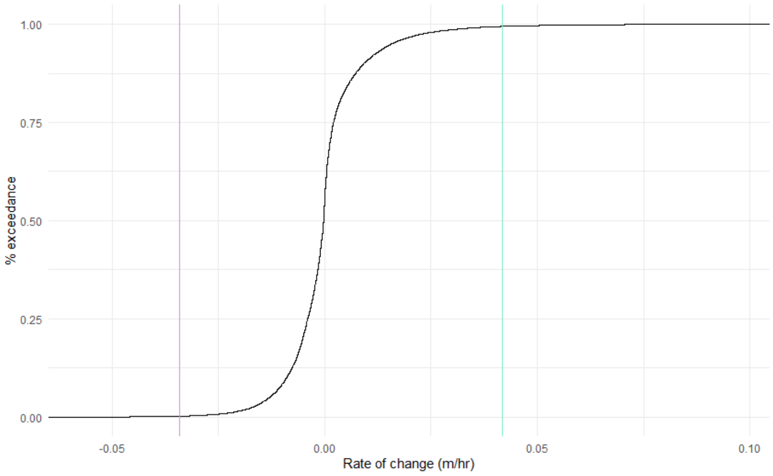


Figure 3: Hourly Loch Awe level fluctuations

The variability in Loch Awe can also be assessed over longer time periods using the daily level data. This shows that a fluctuation in level of 20 cm, corresponding to approximately five hours of operation, is within the range of fluctuation from one day to the next, though the median fluctuation between two days is 6 cm. A level fluctuation of 40 cm (around 10 hours of operation), is within the observed daily variation but at the 98th percentile. However, over longer time periods there are higher fluctuation in loch levels. For example, the median fluctuation within a two-week period is 50 cm.

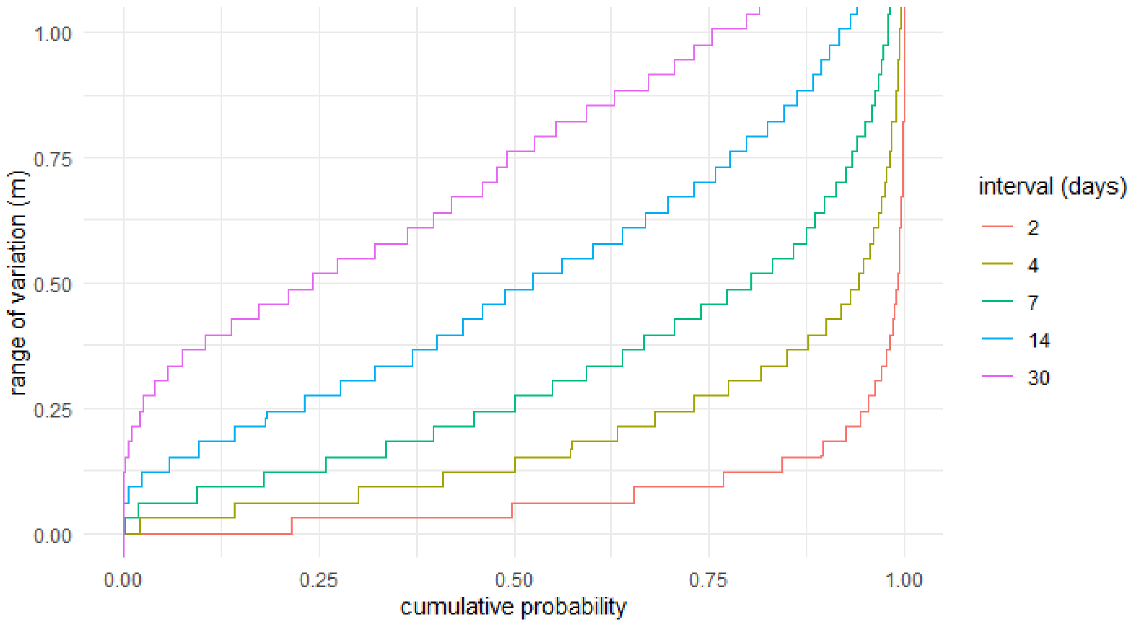


Figure 4: daily to monthly Loch Awe level variability

4.2 Perturbation following single operation

Due to the high rate of pumping water either into or out of Loch Awe, the Development operation has a significant impact on Loch Awe water levels. The required duration for loch levels to return to within 1 cm of their baseline level after a single operation of abstraction or generation are summarised in *Table 4*. Given the duration of operation required to generate or abstract 100% of the Hheadpond (30 hours), the Abs1 and Gen1 scenarios are extreme scenarios. Alteration of Loch Awe levels influences the ability of the Loch Awe Barrage and Cruachan to generate electricity.

Table 4: Loch Awe level changes

Scenario ID	Run time	Average change in level (m)	Average rebound time (days)
Abs1	30	- 1.07	18.8
Abs2	15	- 0.53	17.1
Abs3	10	- 0.36	14.4
Abs4	5	- 0.18	11.0
Gen1	30	1.13	14.8
Gen2	15	0.62	13.5
Gen3	10	0.42	12.5
Gen4	5	0.22	10.6

4.3 Impact on low flows

The outflow from Loch Awe during periods of low loch levels is an area of uncertainty due to the lack of detail on the fish pass structure. Compensation and freshet flow requirements for different months are published by SEPA annually. Under condition 4.2.3 of the licence “when the inflow to Loch Awe falls below 15.785 m^3/s the outflow shall be equal to the inflow”. It is unknown how this inflow rate to Loch Awe is calculated.

The 95th percentile loch level (35.97 mAOD) has been assumed to be sufficient to allow compensation flows downstream. Therefore, setting this level as the hands-off limit for abstraction from Loch Awe will ensure that the scheme has negligible impact on the provision of compensation flows.

4.4 Cyclical operation

Cyclical operation of the Development alters the Loch Awe level by approximately 15 cm compared to the baseline. For the period of the day outside of the scheme operation, the loch level adjusts over approximately 10 days to balance outflows with the adjusted average loch level. The direction of this change depends on whether abstraction or generation begins the cycle, but the level outside of operating periods is within 5 cm of the baseline level. These level changes suggest that if the Development is operated with net zero daily volume change the impact on loch levels is minimal.

5 Conclusion

The impact on Loch Awe levels due to the Development has been assessed.

Due to the limited information available about the operation of the Loch Awe Barrage and inflows from ungauged catchments a water balance model was set up to determine an average level-discharge relationship for Loch Awe. This assumed relation allowed a reservoir model to be developed to assess the likely change in loch level due to cyclical or single operation of the scheme.

During operation of the scheme Loch Awe levels are predicted to change by -3.4 cm/hr for abstraction, and +4.2 cm/hr during generation. Operating a full cycle of generation or abstraction changes the level of Loch Awe by over 1m, however this scenario is unlikely to occur in practice.

To mitigate the impact of level changes on fish passage, an operating limit based on the historical variation of Loch Awe is proposed. Abstraction from Loch Awe will not occur when Loch Awe is below 35.97 mAOD.

An upper operating limit is developed as part of the flood risk assessment.

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