Loch Kemp Storage - EIA Report

Appendix 7.1: Loch Ness PSH – Hydrological Modelling Technical Note

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ash

ash design + assessment
Suite 2/3, Queens House
19 St Vincent Place
Glasgow, G1 2DT

Tel: 0141 227 3388
Fax: 0141 227 3399

Email: info@ashglasgow.com
Web:
www.ashdesignassessment.com

Loch Ness PSH – hydrological modelling

Technical Note

Project:	Loch Kemp Storage Ltd: Loch Ness modelling to support Kemp PSH		
Our reference:	100111697	**Your reference:**	
Prepared by:	Peter Ede	**Date:**	25 October 2023
Approved by:	Peter Ede	**Checked by:**	Aminul Chowdhury
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1 Introduction

This technical note, commissioned by Loch Kemp Storage Limited (LKSL), reviews the potential impact of current and proposed pumped storage hydro (PSH) schemes on the water level regime in Loch Ness.

2 Background

There is a long-established hydropower scheme at Foyers, firstly from 1896 as a standard scheme generating electricity from water released from Loch Mhor, and since the 1970s as a pumped storage scheme using water pumped up from Loch Ness in addition to the natural inflow to Loch Mhor and some flow diverted from other parts of the Loch Ness catchment. Operation of the scheme adds short-term (typically diurnal) variation in loch level to the natural variation that results from the varying balance between rainfall, inflow and outflow.

Several other PSH schemes have been proposed; when operational the loch level would be subject to greater variation.

3 The loch level regime

Loch Ness is the largest freshwater lake or reservoir in Great Britain, both by area and volume. It drains a catchment area of about $1800km^2$. The large surface area (about $56km^2$) provides a substantial smoothing effect on flows – whilst a severe flood could see peak inflows in excess of $3000m^3/s$ the peak outflow to the River Ness would not exceed $1000m^3/s$. In normal conditions the loch level varies within a range of about 1m, but in a severe flood event would go significantly higher.

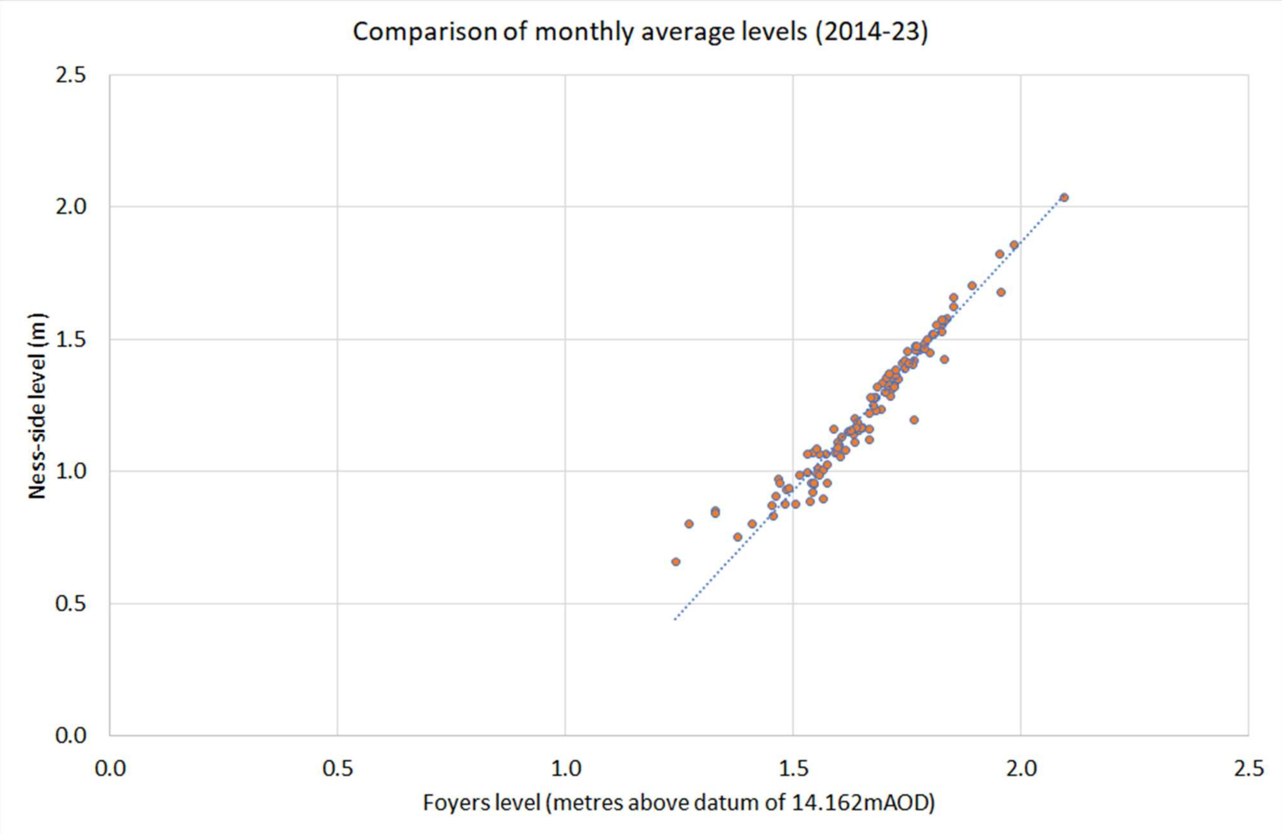
The longest current record of loch level is at Foyers where records date from April 2014 on a 15-minute time step. Other historic records include Fort Augustus and Dochgarroch; whilst of interest, these are at the extremities of the loch and are likely to be less representative than Foyers. The Foyers record shows a range from 15.25 to 17.52mAOD, though a higher Loch Ness flood level of 18.02m was reported in the February 1989 event.

The SEPA gauge at Ness-side, on the River Ness downstream of Loch Ness, provides a longer-term perspective with records of water level and flow from September 1972 to date. Conditions at Ness-side are closely related to those at Foyers because a rise in the loch level leads to increased outflow over Ness Weir which means higher levels and flow at Ness-side. The relationship is illustrated in Figure 3.1 which compares average monthly water levels (referenced to each site's local datum). There is a small additional catchment contributing to the River Ness between Loch Ness and the Ness-side gauge, but the flow pattern at Ness-side essentially represents the loch outflow.

There is a broadly linear relationship, but with deviation at lower levels where the operation of the SSE sluice at Ness Weir significantly affects the outflow from Loch Ness and hence the water level at Ness-side. May and June 2023 show the lowest loch levels in the period of record, in line with recent media reports. The next lowest were in 2021 which was another notable dry summer.

We have not seen any documentary evidence about the operation of the sluice. We understand from the Scottish Canals Water Control Manual V12 for the Caledonian Canal that the minimum compensation flow is $28.3m^3/s$. During low loch levels the model assumes the SSE sluice opens to maintain this flow as a minimum into the River Ness. Any change in the compensation assumption would have an impact on the frequency of occurrence of low loch levels but would have negligible impact on average or high levels. Modelling of sluice opening in closed and partially or fully open scenarios concludes that these sluices do have a significant effect on the frequency of low flows in Ness Side and levels generally in Loch Ness and at Ness Weir.

Figure 3.1: Comparison of water levels at Foyers and Ness-side

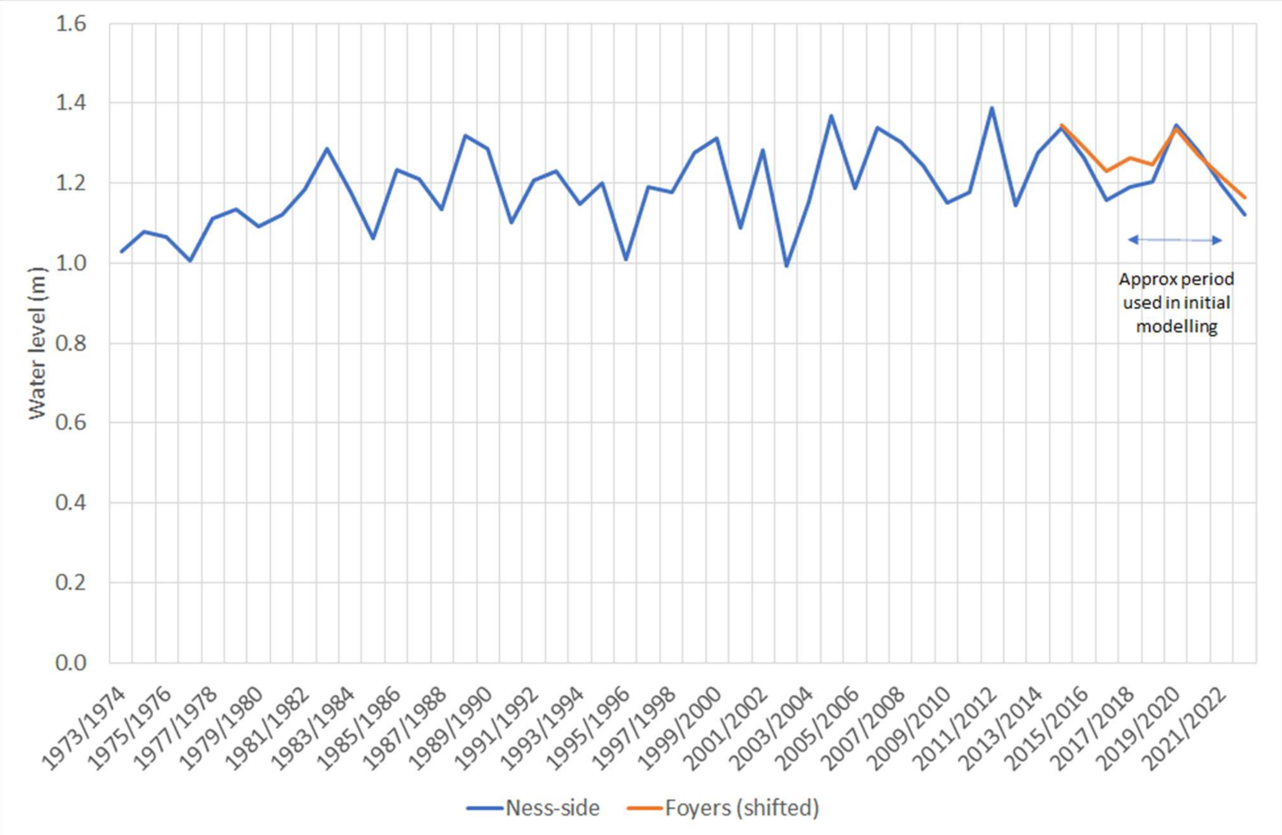


Source: Data from https://beta.sepa.org.uk/HydroDemonstrator/Stations

Figure 3.2 compares the annual mean levels and places the recent period in context by showing the full period of Ness-side data. In order to maximise the number of years of Foyers data the averages are for years from 1st July to 30th June. The Ness-side data shows a clear increase in the 1970s and 1980s; increases over this period have been seen at many sites in the west of Scotland, reflecting a widespread increase in rainfall. Since about 1990 there is no obvious trend, and the period used for initial modelling[1] appears broadly representative of that longer period. The Foyers data shows a smaller range of levels than at Ness-side, reflecting the very large surface area of Loch Ness compared to the small river cross-section.

[1] 2017-22, as data availability was limited because of the cyber attack on SEPA.

Figure 3.2: Comparison of annual average water levels at Foyers and Ness-side



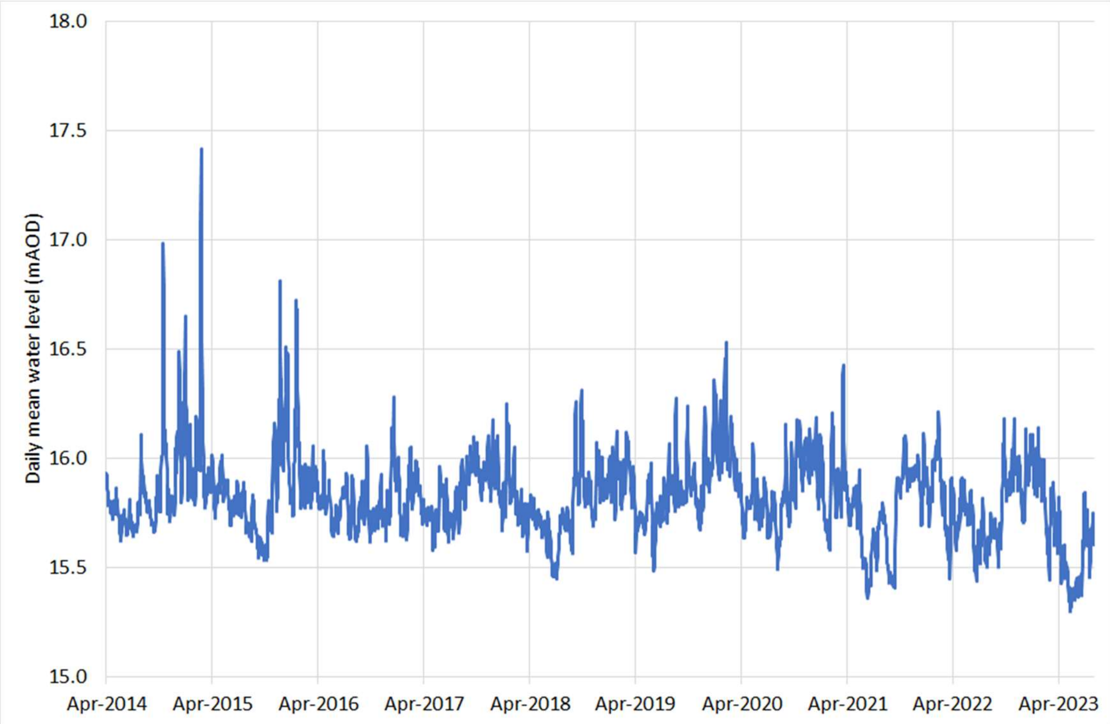
Source: Data from https://beta.sepa.org.uk/HydroDemonstrator/Stations

The variation in daily mean loch level over the period is shown in Figure 3.3. The extreme levels in the period are 17.42m on 8 March 2015 and 15.32m on 28 May 2023. The 15-minute data shows slightly more extreme values of 17.52 and 15.25m. With a wet year at the start and a couple of dry years towards the end the graph has a suggestion of a downward trend, but the data set is too short for drawing conclusions.

The variations in level reflect the historic operation of Foyers as well as rainfall, loch inflows and the operation of the SSE sluice. We do not have data on Foyers operation, but can infer something about the operation from the level data. The average level through the day, from the full period of data, is shown in Figure 3.4; this shows a decline from about 2300 to 0600 (reflecting typical pumping up during the night when demand is low and electricity prices usually below average) with rises through the day (when there are releases to generate power to meet demand), excepting a period of slight decline between about 1230 and 1530. However, it should be noted that future operation will not necessarily follow a similar pattern, as this may be driven by changes in availability of power from other sources (eg wind) as well as changes in overall demand for electricity.

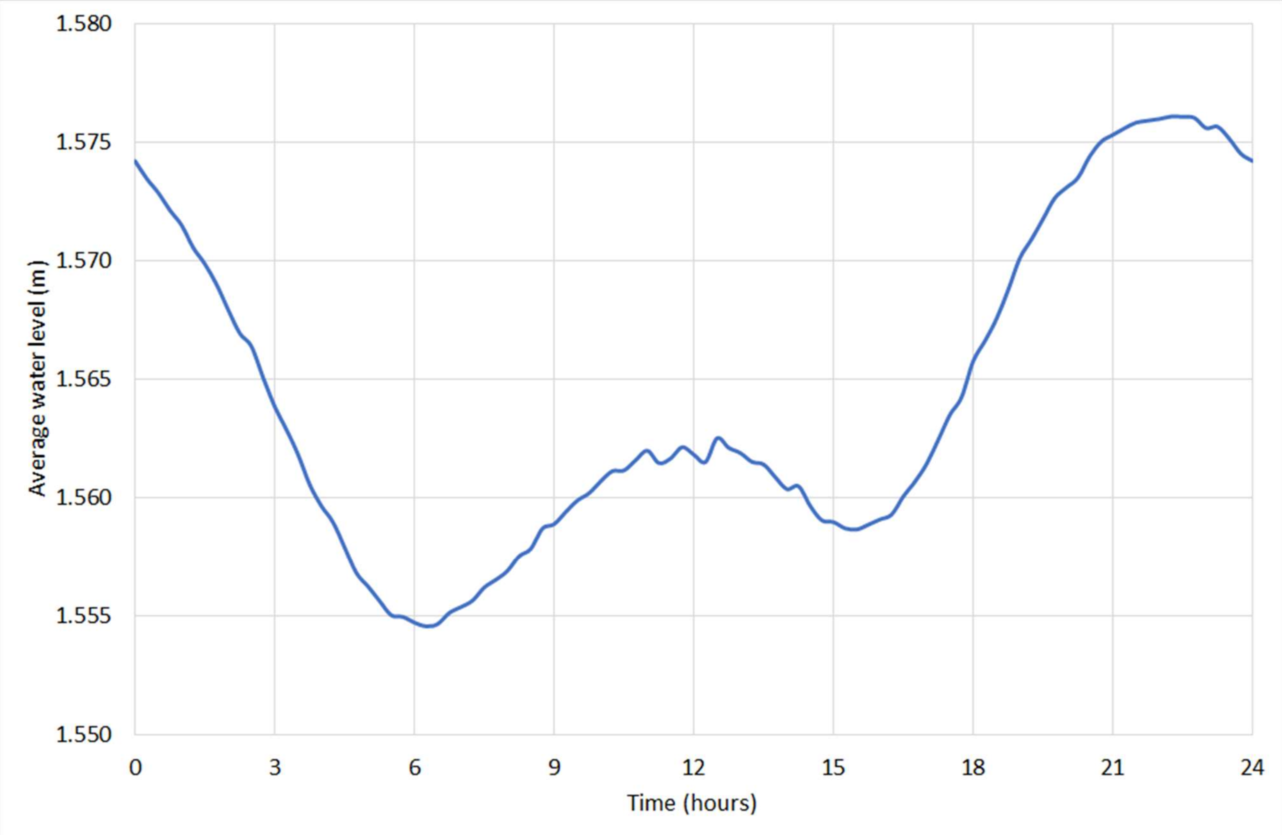
The 15-minute fluctuations in loch level for a sample 2-week period in 2022 are shown in Figure 3.5.

Figure 3.3: Daily mean water levels at Foyers



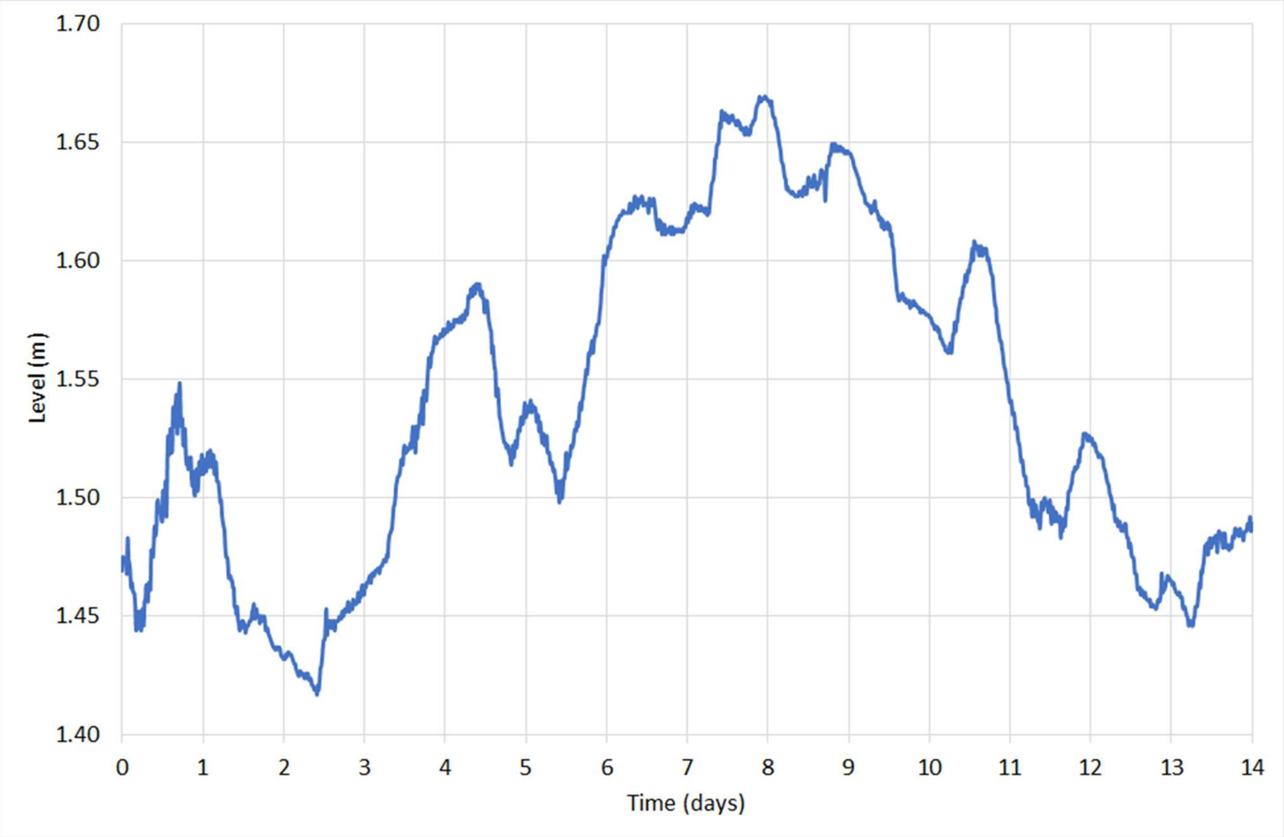
Source: Data from https://beta.sepa.org.uk/HydroDemonstrator/Stations

Figure 3.4: Average diurnal pattern of Loch Ness levels



Source: MM analysis of data from https://beta.sepa.org.uk/HydroDemonstrator/Stations

Figure 3.5: 15-minute Loch Ness levels for a sample period



Source: Data from https://beta.sepa.org.uk/HydroDemonstrator/Stations

4 Modelling

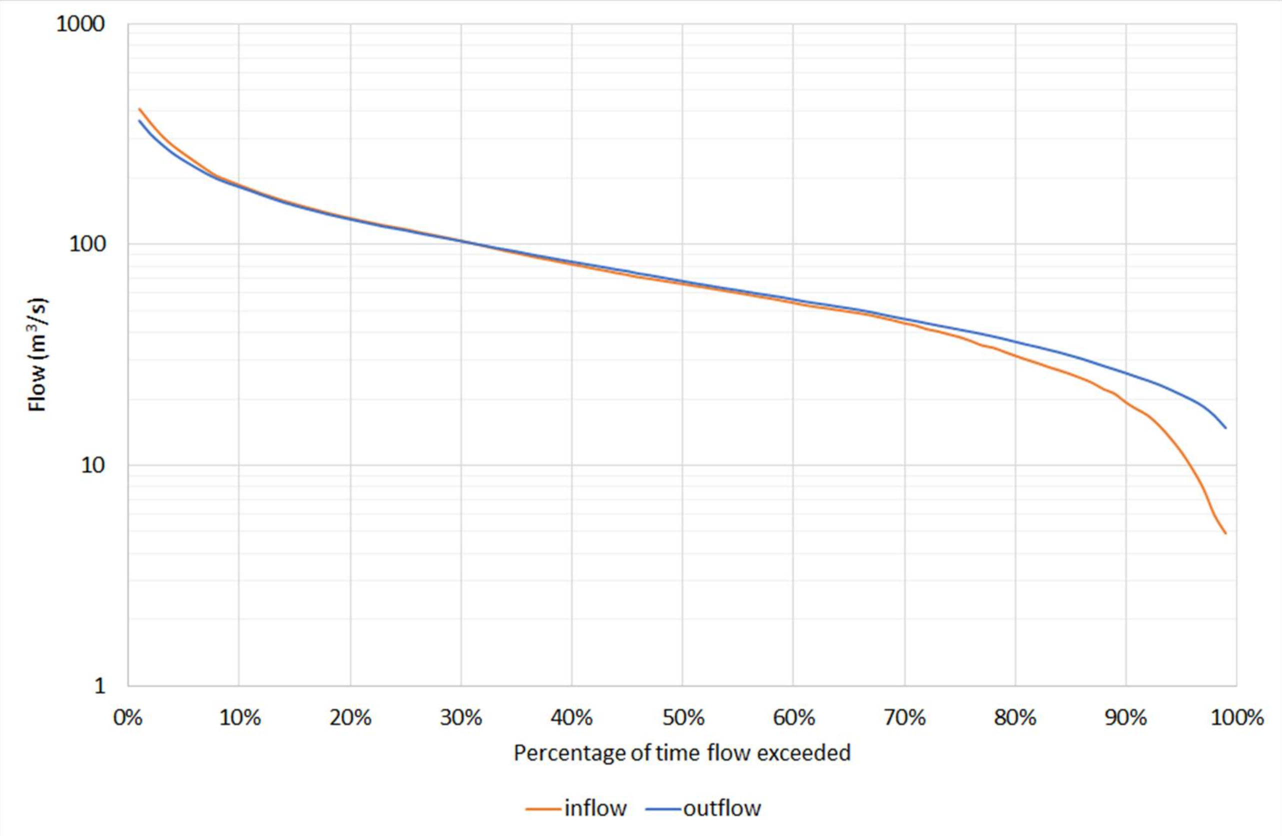
4.1 Model structure

Water balance modelling was undertaken to simulate the effects of PSH operation on loch levels. This was initially for a period of just under 5 years up to March 2022, based on the availability of data at the time. Although Figure 3.2 shows this period to be reasonably representative of longer-term conditions it is desirable to use a longer period to ensure that a wide range of conditions are included in the analysis.

The initial modelling used estimated loch inflows derived from loch outflows and the change in loch storage. The attenuation provided by the loch means that outflows show less variability than inflows, as illustrated by the flow duration curves (FDCs) shown in Figure 4.1. There is a reduction in high flows (roughly the top 10% of daily values) and an increase in low flows (particularly the lowest 30% of values). It may appear that the changes do not balance out, but this is a result of the log scale of the graph; the difference at the top end (flow exceeded 1% of the time) is almost 50m^3/s whereas at the other end (flow exceeded 99% of the time) the difference is only about 10m^3/s.

The relationship between the FDCs for the initial modelling period was used to produce a 50-year synthetic inflow series from the flows for Ness-side (approximately representing loch outflows) for the period 1973 to 2022. Whilst this does not accurately simulate inflows for specific periods (such as a recorded flood event) the overall characteristics of the synthetic series are considered satisfactory for undertaking long-term simulations of loch levels where the aim is to estimate the change in loch level that would result from PSH operation rather than the precise level on any particular day.

Figure 4.1: Flow duration curves of loch inflow and outflow



Source: MM analysis

The model operates on an hourly time step, with inflow assumed constant for the 24 hours of each day. The outflow is determined from the rating curve obtained from hydraulic modelling of Ness Weir and the rest of the system, subject to the requirement to release at least the assumed compensation of 28.3m^3/s.

4.2 PSH operations

We understand that there was an agreement between SSE and the then British Waterways that SSE should maintain a minimum level in Loch Ness of 15.27mAOD; this is therefore the level at which Foyers must stop pumping water from Loch Ness to its upper reservoir. It is expected that future schemes will be subject to regulation by SEPA and that stop-pumping levels will be defined in CAR licences. SEPA regulation might apply to Foyers in future.

The preliminary CAR licence application for Kemp proposed a stop-pumping level of 15.33mAOD for Kemp. A slightly higher value (15.42m) was used in the modelling work, with an intermediate level (15.38m) assumed for Red John. Setting higher thresholds for future schemes is intended to protect the existing scheme and avoid extreme loch levels. The extent of curtailment of PSH operation would be affected by any change to threshold levels, but there would be no fundamental change to the impact on the water level regime described below.

Application of the Foyers threshold of 15.27m does not guarantee that the loch level will not drop below that value, because in a drought loch inflow may be lower than the assumed compensation. SSE may be able to support Loch Ness levels by operating other schemes within the catchment, but this has not been incorporated in the modelling.

As already noted, the natural level of Loch Ness varies relatively slowly because its size and ability to temporarily store water provides a dampening effect on variations in inflow. With PSH operation short-term fluctuation in level is superimposed on the natural variation. This is typically over a matter of hours; Kemp, for example, could generate at its maximum rate for about 15 hours, but may well involve shorter cycles, ie part emptying of the upper reservoir followed by refill, rather than complete emptying.

Analysis of likely PSH operation in 2030 was undertaken by Lane Clark and Peacock LLP (LCP) for LKSL and provided for this study. The LCP profile gives an hourly profile of generation or pumping (expressed as a percentage of the maximum possible) for 365 days. A suitable day was identified to copy to “day 366” for use in leap years. The modelling has assumed a “worst case” of all schemes operating in sync – with the exception that pumping for a particular scheme would cease if its upper reservoir is full, and generation would cease if the upper reservoir is empty. In practice Red John (which has much lower capacity) might have an additional cycle of generation and refill rather than lying idle.

Based on our assumptions for the operation of the SSE sluice, our assessment concludes that PSH operation means that the minimum level in Loch Ness will be approached more often, but the absolute minimum level would not significantly change. The overall range of levels will slightly increase because releases for generation cause a temporary increase in level before the resulting increase in flow over Ness Weir brings the level back down. The small scale of changes in level is shown in the next section.

Although we are not aware of any restriction on the operation of Foyers when Loch Ness levels are high, it is expected that future CAR licences would have a “stop-generation” threshold when releases from upper reservoirs would have to stop in order to avoid worsening flood conditions downstream. The preliminary CAR licence application for Kemp proposed a stop-generation level of 17.44mAOD, based on the expected level in a 1-in-10 year flood event[2]. Curtailment of operation due to this threshold would be limited as it would only occur once every ten years on average, and for a limited period, typically up to 5 days. In the modelling the stop-generation level has been applied to all schemes.

4.3 Scenario variations in loch level

The schemes considered for this review are listed in Table 4.1.

Table 4.1: Loch Ness pumped storage schemes

Scheme Name	Upper reservoir storage volume (Mm^3)	Capacity (MW)	Flow at maximum power (m^3/s)	Maximum run time generating (hours)	Modelled stop pumping level in Loch Ness (mAOD)	Direct catchment area (km^2)	Status
Foyers	15	300	200	21	15.27	200	Operational
Red John	5	450	220	6	15.38	0	Consented
Loch Kemp	21	600	392	14.8	15.42	4.1	Scoping

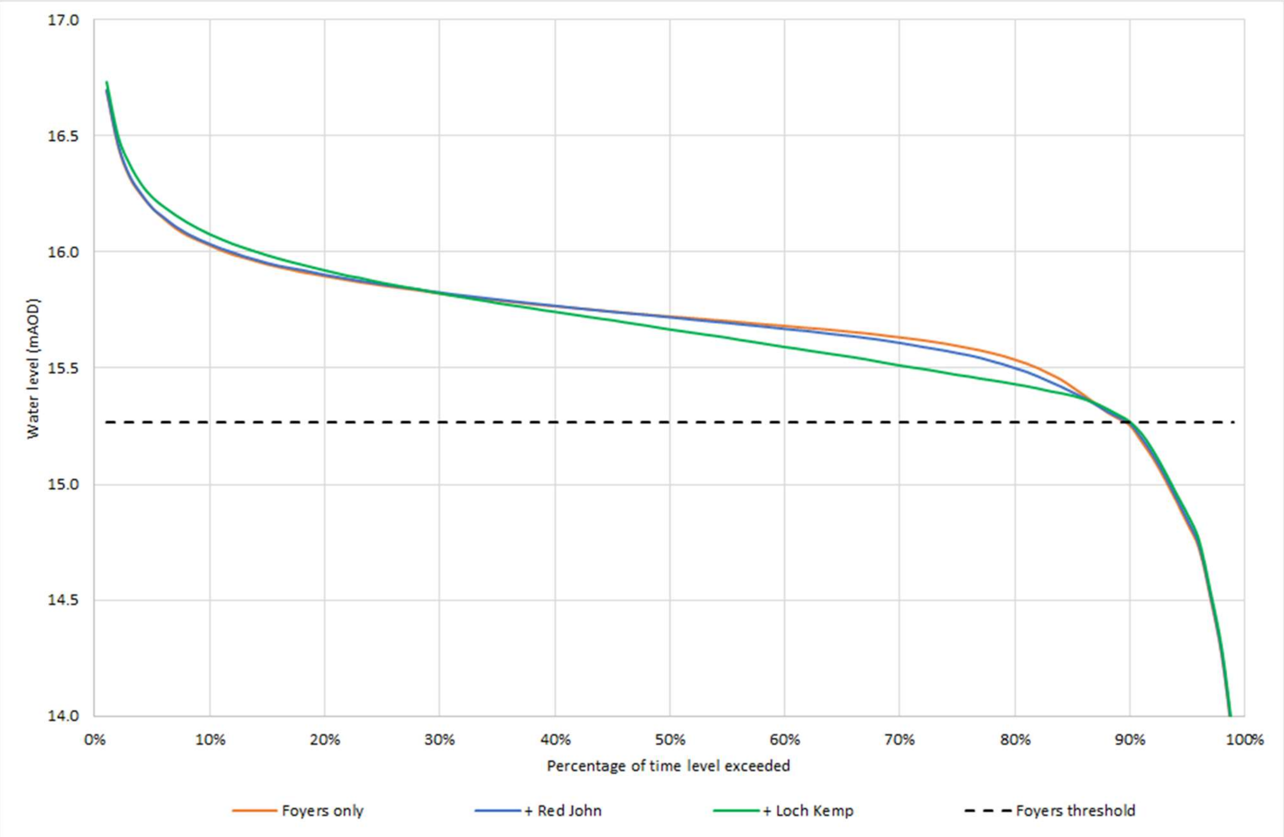
One of the key means of illustrating the changes in loch levels due to PSH is the level duration curve (LDC); this shows the level plotted against the percentage of time that the level is exceeded (Figure 4.2). Selected points from the LDC are also tabulated in Table 4.2 – these range from L1 (the level exceeded 1% of the

[2] Updated analysis using the hydraulic model rating curve has revised this estimated level to 17.45mAOD.

time, 3-4 days per year on average), through L50 (the median level) to L99 (the level exceeded 99% of the time). As noted above, the analysis assumed that all schemes would operate in sync. If that doesn't happen then impacts would be reduced. The impact of the schemes is cumulative, with Kemp leading to the larger change because its storage capacity is much larger than that of Red John. It should also be noted that the results shown for the "Foyers only" case are an estimate of what has already happened compared to an assumed "natural" condition, based on the LCP profile that will differ from actual historic operation. Two potential future changes are shown, firstly that between "Foyers only" and "+Loch Kemp" (the difference due to both Red John and Loch Kemp), and secondly that between "+Red John" and "+Loch Kemp", ie the difference due to the Loch Kemp scheme.

For the lowest levels there is very little difference between the curves because the schemes would not be operating at such levels. There is then a reduction in levels over about half of the curve (L85 to L30), followed by smaller increases at higher levels. Overall the changes are considered minor, with Table 4.2 showing these to be up to 10-12cm. The largest change occurs at about L70. There is a slight reduction in the overall average level as schemes are added.

Figure 4.2: Loch Ness level duration curves for various scenarios



Source: MM analysis

Table 4.2: Estimated levels (mAOD) for selected points on the LDC for various PSH scenarios

	exceedance	Foyers only	+ Red John	+ Loch Kemp	Change from current	Change due to Loch Kemp
L1	1%	16.69	16.70	16.73	0.04	0.03
L10	10%	16.03	16.03	16.08	0.05	0.05
L30	30%	15.82	15.83	15.82	0.00	-0.01
L50	50%	15.72	15.72	15.67	-0.05	-0.05
L70	70%	15.63	15.61	15.51	-0.12	-0.10
L90	90%	15.25	15.26	15.27	0.02	0.01
L99	99%	13.87	13.88	13.90	0.03	0.02
Overall mean		15.67	15.66	15.63	-0.04	-0.03

4.4 Climate change

No specific climate change investigations have been undertaken to date. Climate change projections for Scotland broadly show drier summers and wetter winters. The summers may contain more frequent/longer periods of low loch levels. This would mean that the operation of PSH schemes would be subject to more extensive curtailment. However, there should not be any fundamental change to the nature of PSH impact on loch levels – ie an increase in diurnal variation, slightly increased high loch levels and slightly lower average levels.

There is some potential for PSH to mitigate extreme levels by pumping during flood events and generating in dry periods.

5 Summary

Simulation of the level of Loch Ness over a 50-year period, based on the currently assumed operating parameters of SSE assets, has shown that the operation of pumped storage hydro schemes should have only limited impact on the range of water levels experienced. There would be a small reduction in the average loch level, estimated at 4cm if both the Red John and Kemp PSH schemes are implemented. Conversely, high levels would occur more often, but the 1% exceedance level would rise by less than 5cm if these schemes and Foyers are operating in sync.