FEARNA STORAGE

Fearna Pumped Storage Hydro Scheme
CAR Licence Report

Appendix C – Hydrology Study

September 2025

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MOTT MACDONALD

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Hydrology summary report

February 2025

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Hydrology summary report

February 2025

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Glossary

CAR Water Environment (Controlled Activities) (Scotland) Regulations 2011

HadUK Data from the Hadley Centre of the UK Met Office

GEL Gilkes Energy Limited

GR6J Rainfall-runoff model (in French, modèle du Génie Rural à 6 paramètres Journalier)

Mm^3 Million cubic metres

MW Megawatt

PET Potential evapotranspiration

PSH Pumped storage hydro

SSE Scottish and Southern Energy

1 Introduction

The purpose of this report is to describe the hydrology relevant to the proposed 1800MW Fearna Pumped Storage Hydro (PSH) scheme and the modelling undertaken to demonstrate the impact of the scheme on Loch Quoich.

1.1 Objectives

The objectives of this report are detailed below:

- Summarise the hydrology of the Invergarry catchment and the rainfall-runoff modelling undertaken to produce reservoir inflow series;
- Review Loch Quoich operating data and rules, together with simulated inflows to establish releases that fit the defined rules and target levels;
- Review the Fearna operating profiles developed by energy analysts;
- Produce a daily water balance simulation model for Loch Quoich and Loch Fearna PSH covering the 1981-2024 period;
- Run the model and review impacts on water levels in Loch Quoich.

1.2 Report structure

The report is structured as follows:

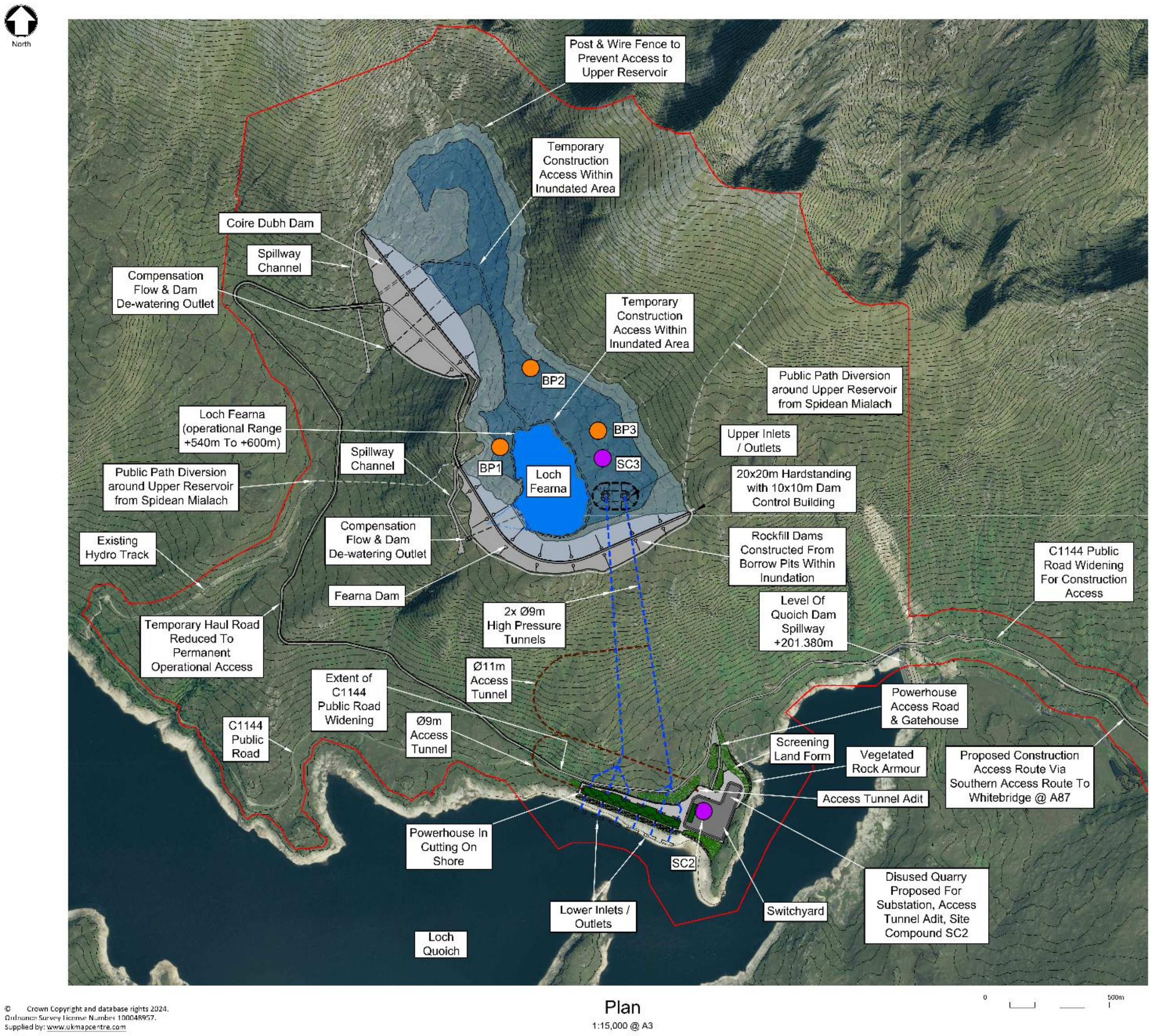
- Section 2 provides background on the proposed Fearna PSH;
- Section 3 summarises the rainfall-runoff modelling undertaken to produce simulated inflow series for use in the reservoir simulation model;
- Section 4 describes how the baseline model of Loch Quoich was developed, and how the Fearna PSH scheme was incorporated into it, including description of the predicted operating profiles and how they have been incorporated in the modelling;
- Section 5 presents the results of the baseline simulation and validation, as well as the incorporation of Fearna and its potential impacts on Loch Quoich; and,
- Section 6 summarises the main findings.

2 Background

The proposed Fearna PSH scheme would use Loch Quoich as the lower reservoir and an expanded Loch Fearna as the upper reservoir (see Figure 2.1). The scheme will be sized at 1800MW with a maximum volume of 41.05Mm^3. Loch Quoich is a large water body with a surface area of 17km^2 and a total storage capacity of about 350Mm^3.

The operation of the Fearna PSH scheme would directly affect the water levels in Loch Quoich, which would influence the head and power generation. It is proposed that the operational range of Loch Quoich be unchanged and that compliance with the conditions of the existing CAR licence (CAR_L_11011471 v2) would be maintained.

Figure 2.1: Fearna PSH schematic



Source: GEL (2024)

3 Catchment flows

3.1 Requirements

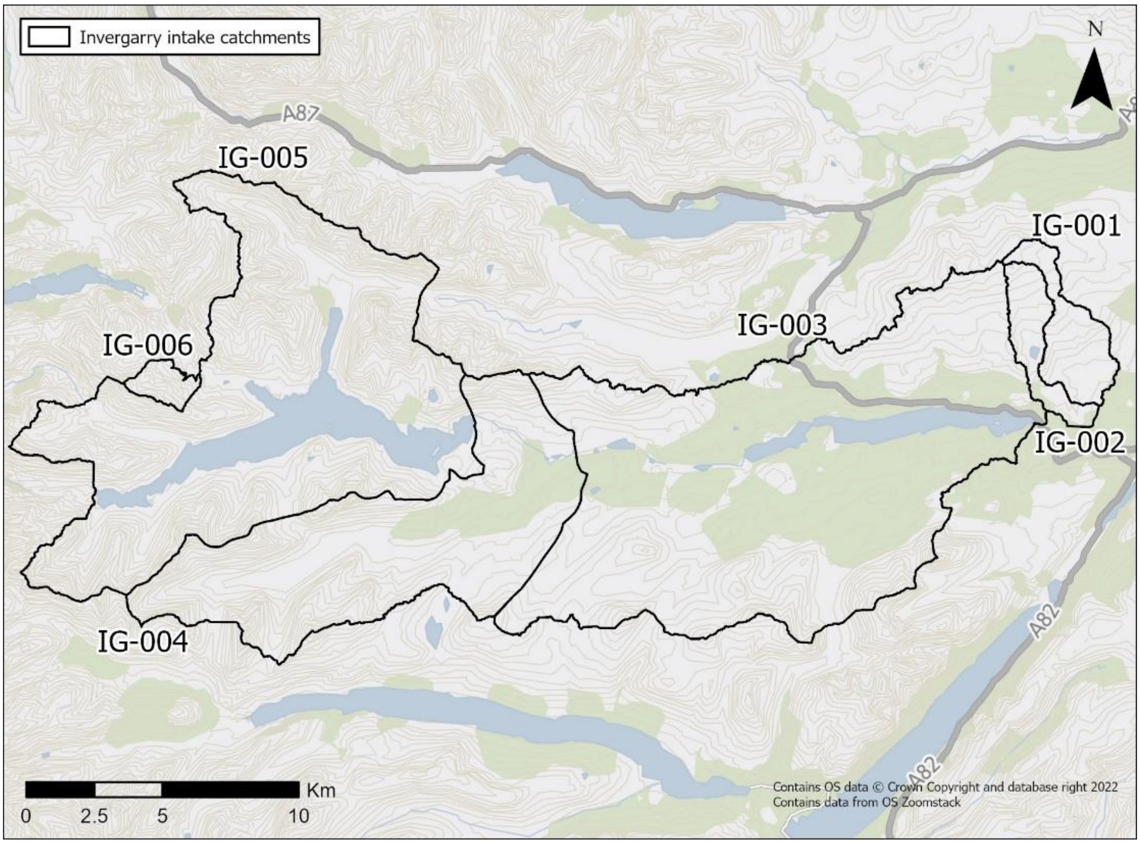
A model to demonstrate the impact of the proposed scheme needs to incorporate flows from the catchments that contribute to the inflows to Loch Quoich. Flow series are required for a sufficiently long period to encompass a representative range of conditions (dry and wet years). Given the large storage in Loch Quoich a daily timestep is appropriate for the flow series.

3.2 Rainfall-runoff modelling

3.2.1 Catchments and data requirements

Rainfall-runoff modelling for the Invergarry scheme was undertaken by Mott MacDonald for Scottish and Southern Energy (SSE) (Mott MacDonald, 2023), using the GR6J model (Pushpalatha et al. 2011) with an associated snowmelt routine. The catchments covered are illustrated in Figure 3.1; only IG-005 and IG-006 are relevant to Loch Quoich. Runoff from area IG-006 is diverted into the main Quoich catchment. The models require series of rainfall and potential evapotranspiration (PET).

Figure 3.1: Invergarry scheme catchments



Data inputs were derived from the Met Office HadUK-Grid Gridded Climate Observations product. The initial work used data for the period 1891 to 2020. For this report updated data to the end of 2024 has been used, though it should be noted that values for 2024 are provisional, based on a limited number of recording stations. Updated 2024 data is expected to be available around September 2025, based on the full set of recording stations and quality control by the Met Office.

Rainfall data was derived directly from HadUK while PET was estimated from climate variables (maximum and minimum temperature, wind, and sunshine hours), all based on the 1km gridded data.

The rainfall-runoff models include snow accumulation and subsequent melting. These use the derived temperature series, with thresholds set in the model to determine when accumulation or melting would occur.

3.2.2 Model calibration

Comparison of initial model simulations and operational data for Loch Quoich suggested that the HadUK rainfall data may understate the true rainfall. Following review of available historical rainfall data, particularly for high elevation raingauges, the final model calibration included a 15% uplift to the HadUK rainfall data.

3.2.3 Data period for scheme assessment

On the basis of the data review it was considered that data from 1981 to date would provide a reasonable representation of current conditions, including an appropriate range of wet and dry years.

4 Reservoir simulation model

A spreadsheet water balance model has been developed to simulate the operation of Loch Quoich, both for the current situation and the potential modifications due to the proposed Fearna PSH scheme. The model uses a daily time step, which is suitable for a large reservoir such as Quoich, but limits the representation of the Fearna scheme. To account for this, the model enables partial pumping and generating to capture the effect of restricted operation of Fearna. The model considers assumptions about the releases for power generation, as well as the compensation releases, additional releases from Quoich if the level gets close to the spillway crest level, and spill when the reservoir reaches its spillway level.

The reservoir model covers a period from 1981 to 2024, and uses operational information provided by SSE. The simulation outputs include the reservoir storage, level, and release for generation. The inputs for the simulation for the year 2024 are based upon provisional data from HadUK and are therefore subject to change when the final data is issued later in 2025.

4.1 Loch Quoich

For the model development, the following assumptions have been made:

- A level-storage equation was derived based on the information provided by SSE. This does not precisely match all level and storage data points provided, but is satisfactory for the purposes of the simulation. This was used to transform target levels into storage, and to convert simulated storage to level;
- The initial reservoir storage for the simulation was set at 148Mm^3, which was calculated from the average end-of-year storage from an initial simulation run. This ensures that the simulation starts from a realistic and representative state of the reservoir;
- Target levels are used to calculate the amount available for release based on current storage and an assumption of average inflows through to the target date;
- Loch Quoich is assumed to spill when the reservoir level reaches 201.38m, where the storage is 362Mm^3; if the reservoir approaches this level additional releases are made through the dispersal valve to minimise the risk of spill occurring
- To satisfy environmental flow requirements, Loch Quoich is required to release at least 0.09Mm^3/d at all times;
- The model incorporates additional releases to support releases from the Invergarry and Glenmoriston cascades that are required under the Ness CAR licence. The total compensation is 0.77Mm^3/d, with 0.58Mm^3/d assumed to be from Invergarry (75%) and 0.19Mm^3/d from Glenmoriston (25%).
- Although observed reservoir storage data provided by SSE runs from 2006 to 2024 it is understood that current operating rules/procedures have only applied for the last few years of the period. Consequently, validation of the model concentrates on the period since 2016.

4.2 Loch Fearna

The model incorporates the proposed Fearna PSH scheme. Based on information provided by SSE and GEL the following assumptions were made for the Fearna scheme:

- Fearna is assumed to be initially half full to fit with the predicted operating profiles which are discussed further in Section 4.2.1;

- Pumping to Fearna is limited by Quoich levels, with a ‘stop pumping level’ below which no pumping is made. This ensures downstream environmental conditions are met;
- Generation from Fearna is constrained by the Quoich levels, where levels are required to be below a ‘stop generating level’ to prevent releases from Fearna causing Quoich to enter flood management mode;
- Potential pumping and generating profiles governing the operation of the scheme were produced based on analysis of energy markets and have been included as options within the model. These profiles are discussed further in Section 4.2.1;
- Fearna is filled to the maximum storage capacity and the maximum volume is released when operational rules allow, as a “worst-case” scenario;
- Fearna is allowed to partially pump and generate in situations where the full operation of Fearna would violate the Quoich level constraints;
- The scheme uses 41.05Mm^3 per full cycle; and,
- Fearna is treated as a closed system with no other inflows or outflows. Its catchment area is very small compared to the Quoich catchment, and for the purposes of this study runoff from its catchment is included in the overall Quoich inflows. This simplification will have minimal effect on the overall assessment.

4.2.1 Operational profiles

4.2.1.1 Hourly profiles

Market analysts provided predicted profiles of hourly scheme operation over the period 2030-2050. These were presented in terms of “state of charge” which effectively means the amount of water stored in Fearna (and available for use to generate energy). The state of charge values were converted to storage values and then the hourly change in storage was converted to a flow volume (of pumping or release for generation). No allowance was made for any minor variations in flow rate to allow for variations in head.

The profiles show average pumping (and generation) of about 14Mm^3/day.

4.2.1.2 Daily profiles

In order to use the profiles in the model (which has a daily time step) the hourly values were converted to daily. On many days the profiles show a mix of pumping and generating, with only a very small number of days showing either full pumping or full generation.

The use of a daily profile that typically involves some netting off of pumping and generation introduces some approximation to the simulation. When the Loch Quoich level is close to one of the control levels this may mean that the simulated pumping or generation is inaccurate (depending on the timing within the day of the pumping and generation). However, in terms of the overall simulation this effect is likely to be very small; furthermore, there will be some occasions when the daily time step leads to over-estimation of scheme operation and others where it leads to under-estimation.

4.3 Overall model usage

The baseline reservoir model (with Fearna switched off) can be validated by comparing outputs to recorded data, and provides a reference scenario for evaluating the potential impacts on Loch Quoich that would result from the proposed implementation of the Fearna PSH scheme. This is covered in the next section.

5 Model Simulation

5.1 Baseline

5.1.1 Validation

The simulation was validated using the observed storage data for Loch Quoich from 2006 to 2024, but concentrating on the most recent period. Figure 5.1 compares the simulated and observed storage of Loch Quoich. The simulation tends to underestimate the observed storage prior to 2016, which can be attributed to the different operational regulations that were in place during that period. Hence, the simulation validation for the pre-2016 period should be interpreted with caution, though there is reasonable correspondence in the timing and shape of peaks in this period.

Figure 5.2 shows storage duration curves for the observed and simulation. There is a lack of agreement between the observation and simulated for the 2006-2024 period, highlighting the difference in operation rules before 2016. The simulated storage agrees well with the observed after 2016, which highlights correspondence with the current operational rules. The discrepancy observed at higher storage levels (0-10% exceedance) is largely due to the high recorded levels in early 2016.

Figure 5.1: Loch Quoich validation (2006-2024)

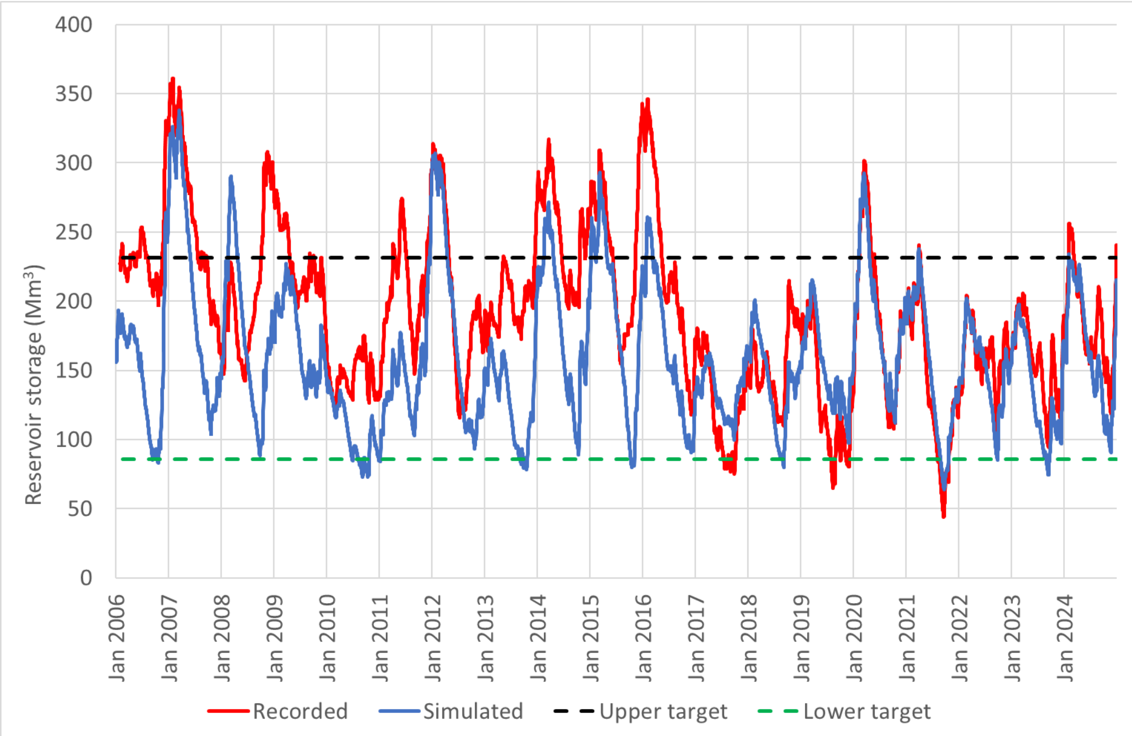
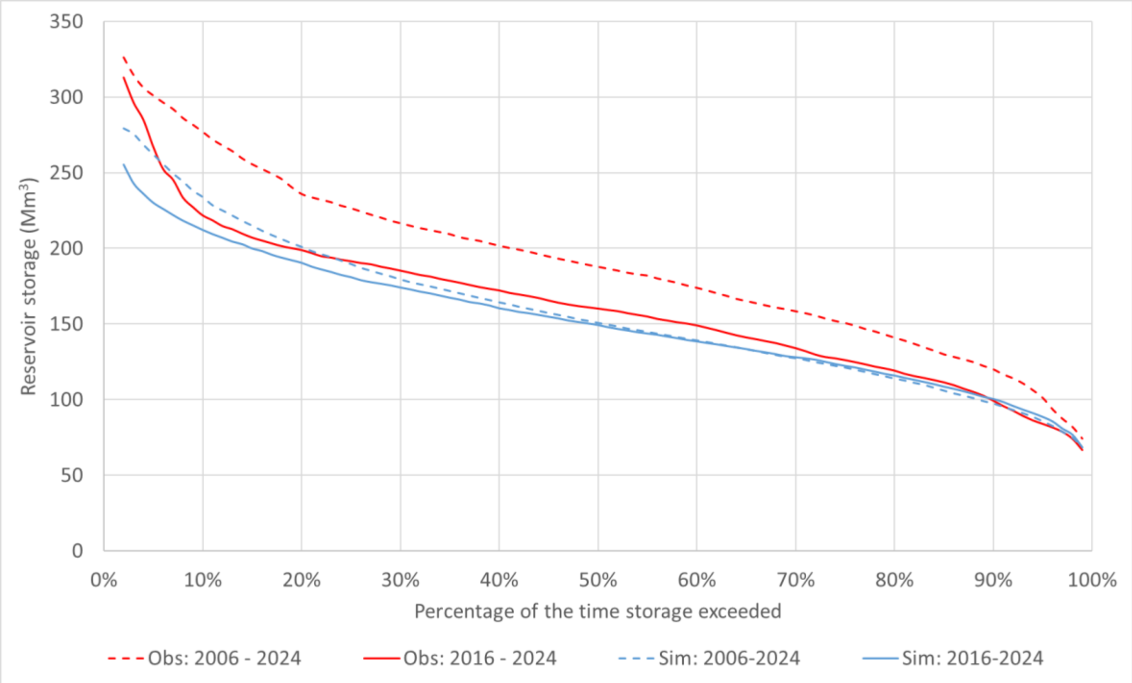


Figure 5.2: Loch Quoich storage duration (2006-2024 and 2016-2024)



5.1.2 Full simulation

The full simulation of the baseline model was performed for the 44-year period of 1981-2024; this assumes the current operational procedures throughout, so outputs prior to 2016 should not be compared to recorded data. The variation in storage of Quoich for the simulation is illustrated in Figure 5.3, which shows the annual fluctuations due to the changes in inflow driven by changes in precipitation and PET. The highest levels are shown in 1989 and 1990 (years with significant flooding in the Ness catchment), with some spill occurring in the 1990 event. Conversely, the lowest level is simulated in autumn 1993.

Table 5.1 summarises the statistics of the baseline simulation. Levels in Loch Quoich range from -21.24m to 0m, with an average of -12.88m. The basic compensation release of Loch Quoich is 0.09Mm^3/d, the environmental regulation of Invergarry and Glenmoriston may require additional releases of 0.49Mm^3/d. However, there are no instances of needing extra release in the 44-year period; on all of the days when the level drops below -20m the adopted rules allow releases for generation that are sufficient to mean that further releases related to the Loch Ness CAR licence are not needed.

This simulation serves as the basis for evaluating the impacts of the Fearna PSH implementation on Loch Quoich.

Figure 5.3: Loch Quoich baseline simulation 1981-2024

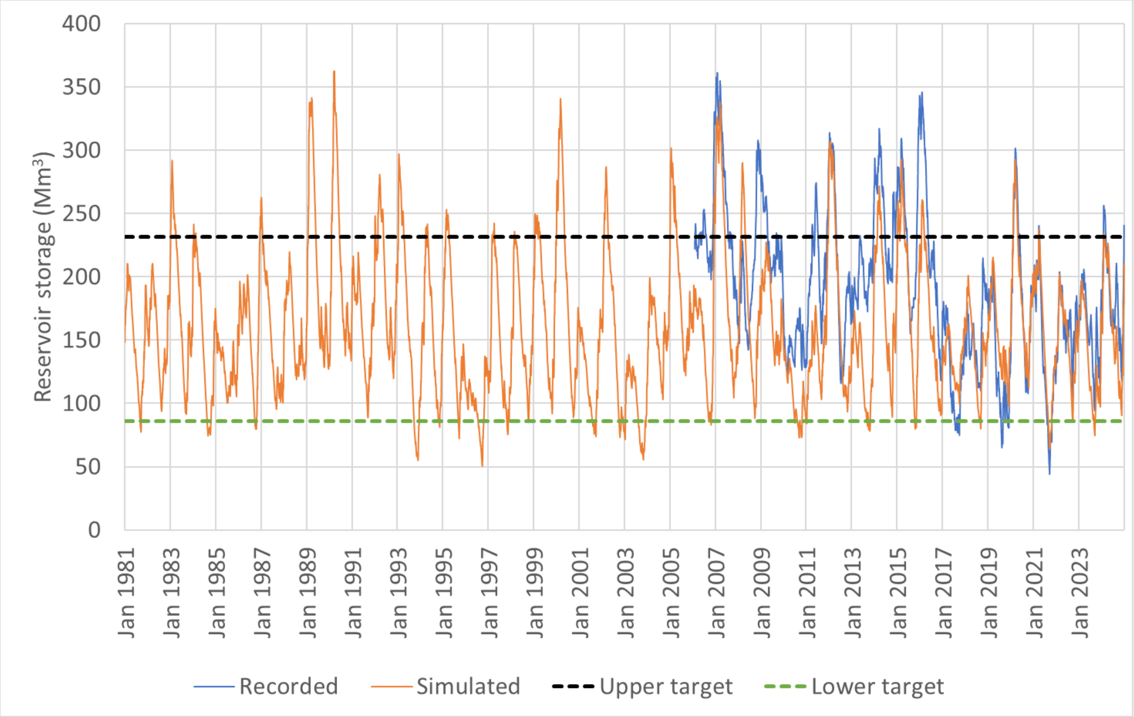


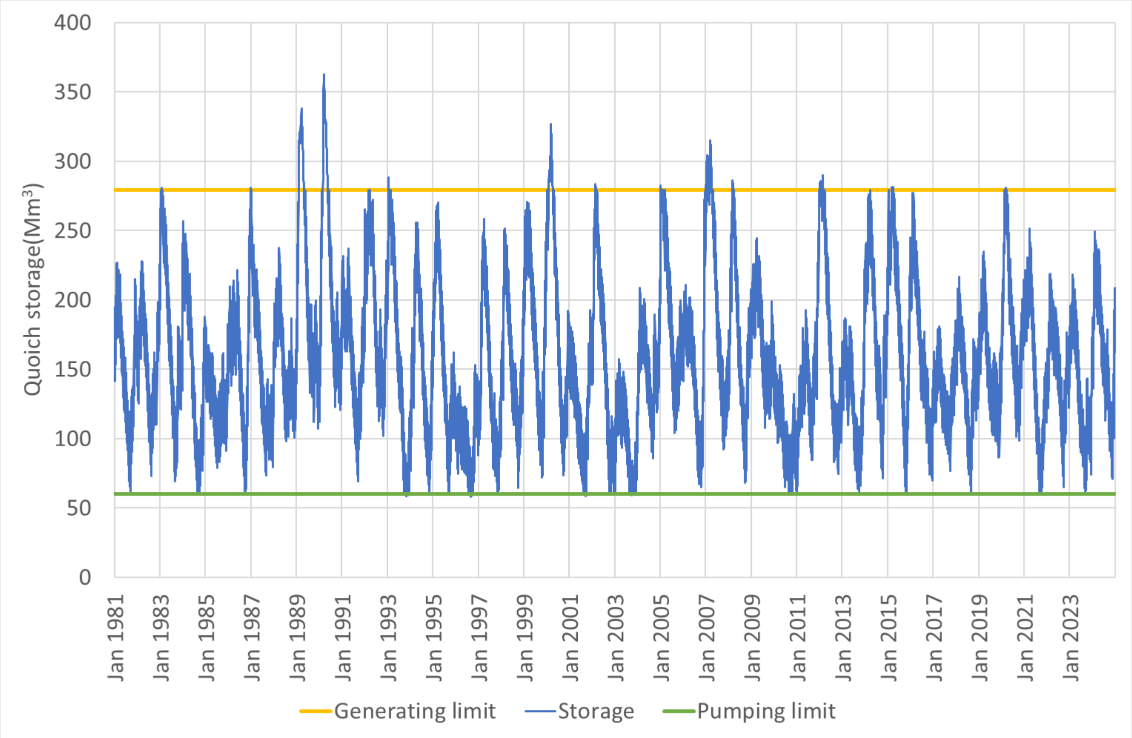
Table 5.1: Quoich baseline simulation summary statistics (1981-2024)

Model output	Full simulation
Average level (m)	-12.78
Minimum level (m)	-20.80
Spill as percentage of average inflow (%)	0.6
Number of days with spill in full period	5

5.2 Incorporating Fearna

The simulation of the Fearna PSH scheme was performed based on the assumptions of the operation of Quoich (detailed in Section 4.1) and Fearna (detailed in Section 4.2). The scheme has a maximum capacity of 41.05Mm³. Figure 5.4 shows the results for the full 44-year simulation (1981 – 2024).

Figure 5.4: Quoich simulation with Fearna 1981 - 2024



5.3 Impact on Loch Quoich

The operation of Fearna PSH could affect the head and power generation of Loch Quoich, as well as the frequency of spill and the downstream compensation flow. Table 5.2 summarises the potential changes in Loch Quoich due to Fearna PSH.

Table 5.2: Summary of Loch Quoich changes

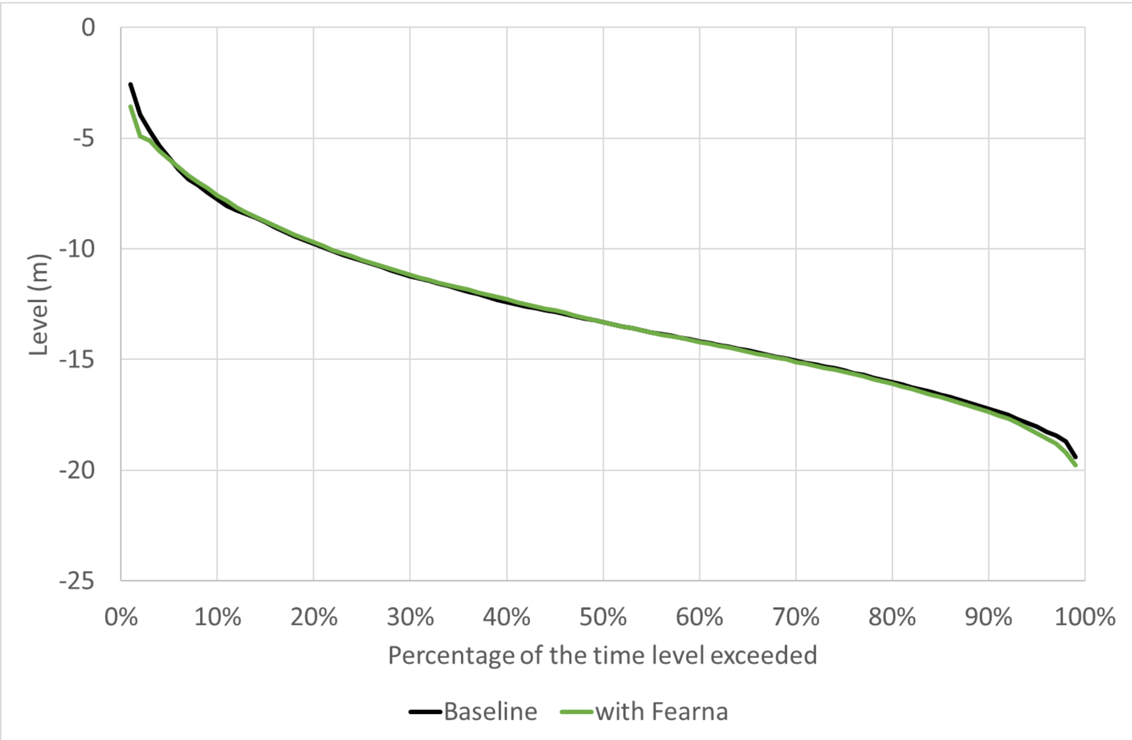
Model output	Baseline	With Fearna
Average level (m)	-12.78	-12.82
Minimum level (m)	-20.80	-20.11
Spill as percentage of average inflow (%)	0.06	0.02
Number of days with spill in full period	5	2

The implementation of Fearna reduces the average level of Loch Quoich by 0.04m because for about half of the time water that would otherwise be in Quoich is held in Fearna. The minimum level of Quoich increases by 0.69m. This is attributed to the operational dynamics of Fearna, which temporarily stores water resulting in delayed reductions of lesser magnitude, increasing the minimum level.

The operation of Fearna decreases the amount and frequency of spill at Loch Quoich. This is due to Fearna's capability to temporarily store water during high levels, subsequently leading to a delayed peak.

Figure 5.5 presents a level duration curve for the baseline and the scheme which shows slight reductions at the top and bottom, but overall not much change.

Figure 5.5: Loch Quoich level duration curve



6 Summary and conclusions

6.1 Development of baseline model

This report presents the development and validation of a water balance model for Loch Quoich, based on the operating rules and information provided by SSE, HadUK PET and rainfall, and simulated inflows from GR6J rainfall-runoff models. The model is validated against observed daily storage data from 2006 to 2024. However, the observed data before 2016 may not be compatible with the modelled operating rules. The model shows reasonable agreement with the observed data after 2016 when the current rules are understood to have been implemented. The baseline model was simulated from 1981-2024 to produce level, storage and release outputs.

6.2 Incorporation of Fearna PSH

The model incorporates the proposed Fearna PSH, which would pump and release water using Loch Quoich as the lower reservoir. The size of the scheme has been defined at 1800MW with a maximum useable volume of 41.05Mm^3. The water levels at Loch Quoich would determine the operation of Fearna PSH, with pumping and generating thresholds. No pumping would be allowed when the level is below the pumping threshold (to ensure water is available to meet Quoich generation) and no generation would be allowed when the level is above the generating threshold (to avoid worsening flood risk).

Profiles governing the operation of the Loch Fearna scheme based upon analysis of energy markets have been included and applied to the model.

6.3 Impact on existing system

The simulation does not indicate any significant changes in the releases for energy generation at Loch Quoich due to the operation of Fearna PSH. Moreover, the simulation reveals that Fearna PSH reduces the occurrence of low levels in Loch Quoich. Fearna PSH operation also reduces the number of days of spill from Quoich as well as the frequency of additional releases through the dispersal valve.

The operation of Fearna introduces day-to-day variation in water levels in Loch Quoich (typically up to about 3m) that is superimposed on the primarily seasonal patterns that occur at present.

7 References

Mott MacDonald (2023) *Rainfall-runoff modelling: Invergarry*

[redacted] (2011) 'A downward structural sensitivity analysis of hydrological models to improve low-flow simulation', Journal of Hydrology, 411(1–2), 66–76. doi: 10.1016/j.jhydrol.2011.09.034.