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Fearna Pumped Storage Hydro Scheme
CAR Licence Report

Appendix I – Assessment of Temperature Variance in Loch Quoich

September 2025

Quality Information

Prepared by	Checked by	Approved by
SLR Consulting Ltd	[redacted]	[redacted]

Revision History

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01	September 2025	Issue to SEPA	[redacted]

Fearna PSH - TUFLOW FV 3D Modelling Report

Assessment of Temperature Variance in Loch Quoich

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Making Sustainability Happen

Revision Record

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1.0	12 August 2025	[redacted]	[redacted]	[redacted]
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Executive Summary

SLR Consulting Ltd. was commissioned by Fearna PSH Limited to undertake a 3D hydrodynamic modelling study using TUFLOW FV to assess the potential thermal impacts of the proposed Fearna Pump Storage Hydro (PSH) scheme on Loch Quoich. This study responds to comments by stakeholders including the Ness District Salmon Fishery Board (NDSFB) regarding potential alterations to natural thermal stratification and downstream temperature regimes, which are critical for sensitive aquatic species such as Atlantic salmon and Arctic charr.

The modelling assessed baseline thermal conditions and the influence of PSH operations under various discharge temperature scenarios. Simulations were conducted for both a short-term (1 month, September 2024) and long-term (12 month, January to December 2022) period. The results demonstrated that Loch Quoich exhibits strong seasonal stratification, with a well-defined thermocline during summer months. PSH operations, particularly under higher discharge temperature scenarios, were shown to cause detectable increases in both surface and bottom temperatures at the dam outtake.

Model validation against observed data showed good agreement, particularly in bottom layers, confirming the model’s reliability. The study concludes that while the PSH scheme may introduce thermal changes, the magnitude and ecological significance of these impacts depend on operational parameters and discharge temperatures.

A 4-year temperature simulation was conducted to assess the cumulative thermal impacts of PSH operations at Loch Quoich, with a focus on the outlet location feeding into the Gear Garry. Despite using a simplified modelling approach with daily temperature outputs and repeated annual flow schedules, results show only a minor temperature increase at the outlet. These findings suggest that sustained PSH operations are unlikely to significantly alter long-term thermal conditions in the loch.

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Acronyms and Abbreviations

EIA	Environmental Impact Assessment
ERA5	ECMWF Reanalysis 5 (Meteorological Dataset)
LCP	Least Cost Path (Energy Scenario)
m AOD	Metres Above Ordnance Datum
m^3	Cubic meter
Mm^3	Cubic megameter
NDSFB	Ness District Salmon Fishery Board
PSH	Pumped Storage Hydro
SMS	Surface-water Modelling System
TUFLOW FV	Three-dimensional Unsteady Flow Finite Volume (Hydrodynamic Model)

1.0 Introduction

SLR Consulting Ltd. (SLR) has been commissioned by Fearna PSH Limited to undertake a numerical modelling study to understand the potential effects of the proposed Fearna Pump Storage Hydro (PSH) scheme on the temperature regime of Loch Quoich.

The purpose of this study is to address the comments raised by the Ness District Salmon Fishery Board (NDSFB) regarding the potential for the proposed Loch Fearna PSH scheme to alter the temperature of water in Loch Quoich. For ease of reference the comments are provided below.

1.1 NDSFB Comments 14.04.25

It is understood that the NDSFB has raised the following concern in its response to the planning application:

Temperature Study

We have noted temperature concerns in the Gearr Garry (bordering on too high at spawning time) with the Gavia temperature study recorded weekly average temperatures around 10°C in mid-Nov. It would not require much of a change from the existing situation to push temperatures into the problematic range. The temperature profile of the Gearr Garry is akin to that recorded in the upper reaches of the River Ness due to the thermal inertia in Loch Ness. Consequently, the Ness salmon are the latest spawning in the Highlands, a situation that would have evolved over millennia.

The temperate study documents the breakdown of the thermocline in Quoich, but doesn’t cover its formation in the spring/summer. We considered it likely that the Fearna scheme will affect the formation of the thermocline, either delaying its formation, or weakening it. Thermocline formation is a natural feature of temperate lakes globally. Thermocline formation means that the lower levels in the loch remain cool, which may be important for charr, and the warmed upper levels provide a more biologically productive zone. Tippet, 1978, recorded a delay in the formation of the thermocline in Loch Awe, in the vicinity of Cruachan and reduced plankton productivity. That is a much smaller pump storage scheme than proposed for Quoich, where the plume is likely to cross the loch with unknown impacts on the natural hydrology. We note that the Balliemeanoch PSH EIA considers the impact of the scheme on thermal stratification in Loch Awe to be Moderate Adverse and Significant, yet we see none of that discussion in the Fearna EIA.

Other comments on the temperature study.

Solar radiation is mentioned several times but there is no mention of the role of wind induced currents, which I understood to be the dominate force affecting loch temperatures. This comment is from Section 5.5 “While incident solar radiation, and the resulting ambient air temperatures are considered the primary driving mechanism on water temperatures within the loch”. My understanding is that wind-driven surface currents in the spring warms the surface layers and establishes the temperature gradient required for thermocline formation.

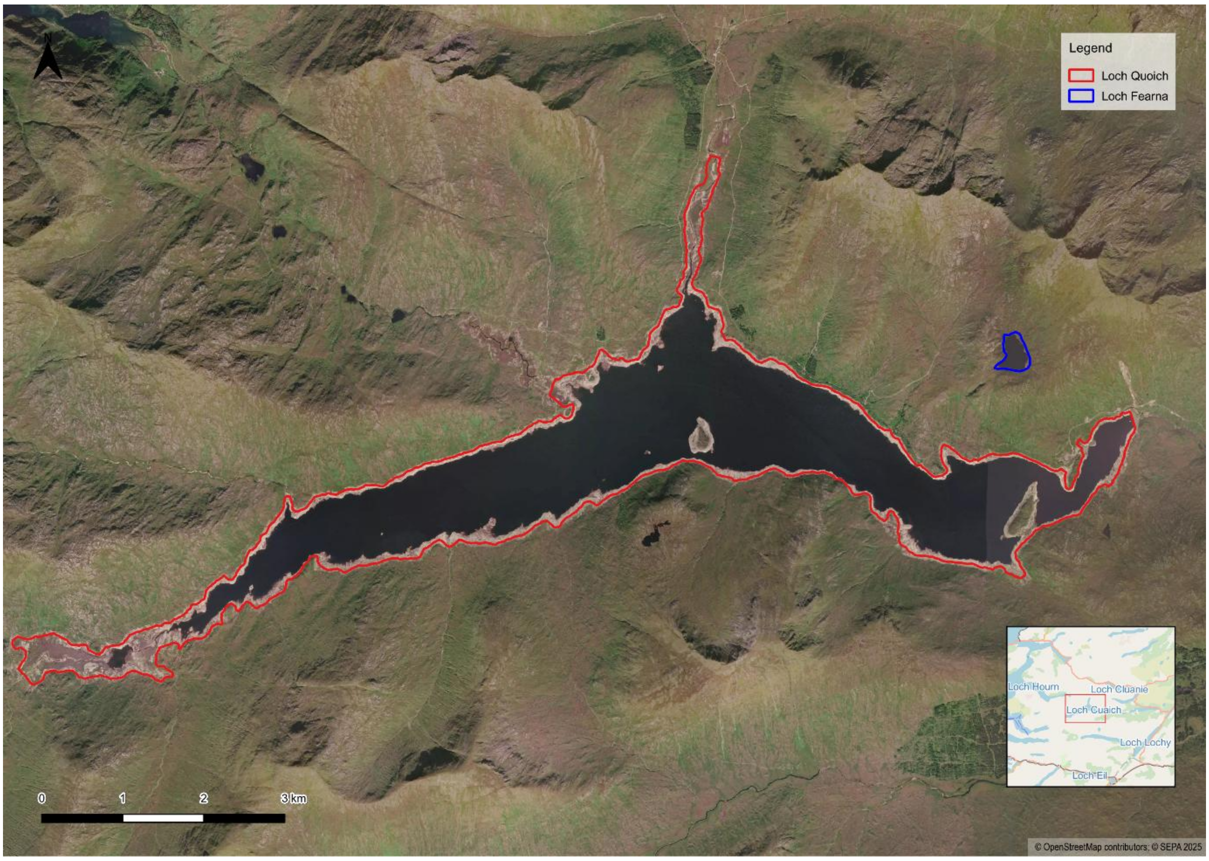
1.2 Background

To address these concerns and quantify potential effects on the thermocline in Loch Quoich and temperature variation in the Gearr Garry, the industry standard TUFLOW FV[1] hydrodynamic modelling package was utilised.

This report presents the hydrodynamic methodology adopted for the study, including details of input data, modelling setup, and the results of the assessment.

The proposed PSH scheme is located at the downstream end of Loch Quoich, west of Loch Garry and approximately 40 km northwest of Fort William, Lochaber, Scotland. Loch Quoich is centred on National Grid Reference NH 01473 02543 as shown by Figure 1-1.

Figure 1-1: Loch Quoich and Loch Fearna Locality



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[1] https://www.tuflow.com/products/tuflow-fv/

2.0 Methodology

TUFLOW FV is a powerful finite-volume hydrodynamic model designed for both 2-dimentional (2D) and 3-dimentional (3D) simulation of water bodies. Its 3D capabilities allow for detailed representation of vertical and horizontal variations in water properties such as temperature and salinity, making it especially valuable for modelling stratified environments like estuaries, lakes, and reservoirs.

The model can simulate how temperature gradients develop and change over time, capturing the formation of thermal layers and the effects of atmospheric conditions on surface heating and cooling. TUFLOW FV includes detailed atmospheric heat exchange processes, such as solar radiation, longwave radiation, and evaporative cooling, all of which influence water temperature and density.

By accounting for temperature-driven density differences, the model is able to reproduce the resulting circulation patterns and mixing within the water column. It also supports various turbulence closure schemes to better resolve vertical mixing and can incorporate time-varying wind and weather inputs to enhance accuracy. Overall, TUFLOW FV provides a comprehensive and physically realistic approach to modelling temperature dynamics in three dimensions.

To parameterise the TUFLOW FV 3D model the following information was included:

- Available bathymetric survey for Loch Quoich;
- Temperature data (water and air);
- Wind Speed and Direction;
- Offtake flow rates for the dam; and
- Discharge rates, operation, and temperature of the pumped hydro scheme discharging between the loch and the PSH upper reservoir (Loch Fearna).

2.1.1 Simulation Scenarios

Three (3) scenarios were developed to complete this assessment and are summarised in Table 2-1: Summary of simulation scenarios.

Table 2-1: Summary of simulation scenarios

No.	Scenario	Description	Duration	Period	Purpose
1	Baseline	Calibration \ Validation to monitored data, without PSH operation	1 month	September 2024	Assess natural thermocline formation and productivity compared to monitored data
2	Baseline	Long form scenario to assess Loch Quoich over time, without PSH operation	12 months	January 2022 to December 2022	Assess natural temperature regime during colder to warmer period
3	PSH Operation	PSH inflow/outflow superimposed on both baseline periods	12 months	January 2022 to December 2022	Assess impact of PSH plume on stratification and downstream temperatures
4	Baseline and PSH Operation	Long form simulation to assess potential cumulative impacts	4 years	January 2020 to December 2023	Assess cumulative impact of PSH flows

2.2 Hydrologic Inputs

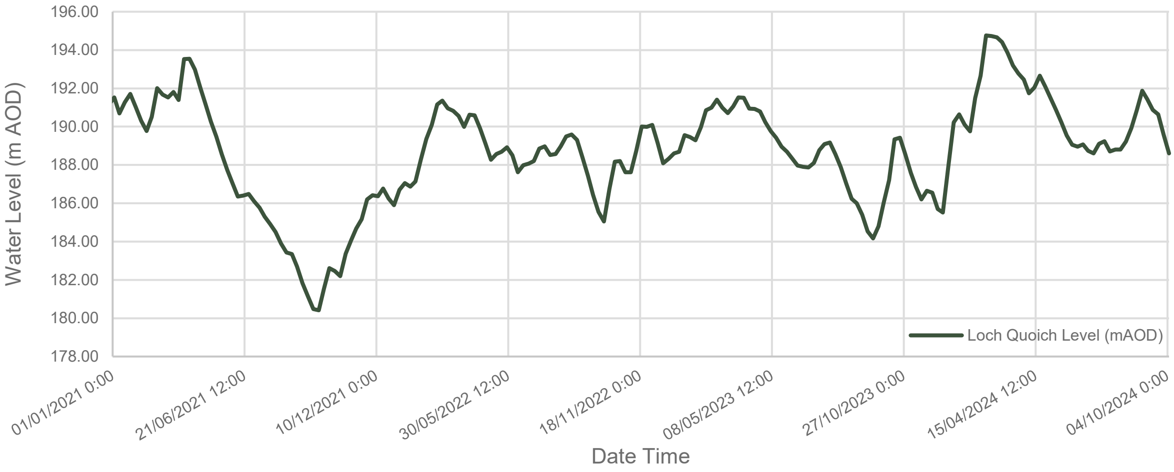
The hydrological inputs to the TUFLOW FV model included Loch Quoich recorded water levels, the PSH Scheme inflow and outflow rates, and the Loch Quoich operational outtake rates.

2.2.1 Loch Water Level Boundary Conditions

External fluvial flows have not been considered at this stage, due to the loch levels being dictated by the hight versus time boundary conditions as provided at the time of this study. This boundary condition drove hydrodynamic circulation across the model domain and was applied at the western inflow location to the loch.

The Loch Quoich recorded water levels for the period of January 2021 to October 2024 is provided in Figure 2-1.

Figure 2-1: Received Loch Quoich Recorded Water Levels



The location of the Loch Quoich water level boundary within the model has been provided in Figure 2-5.

2.2.2 PSH Scheme Inflow/Outflow Rates

The inflow and outflow rates associated with the Fearna PSH scheme were extracted from the file “*Fearna PSH - Predicted Flows 19.05.25.xlsb*”, specifically focusing on the modelled year 2034. While the dataset extends from 2034 through to 2050, the 2034 subset was deemed sufficient for the purposes of this assessment, providing a representative operational year for thermal impact modelling. Analysis of the predicted PSH operation in other years shows that the induced temperature variation between years would likely be insignificant. These flow rates, into and out of Loch Quoich have been summarise in Table 2-2, and raw results within Appendix A.

Table 2-2: 2034 Modelled PSH Flow into and out of Loch Quoich

Month	Sum of Volume into Quoich (m³)	Sum of Volume out of Quoich (m³)
January	381,837,987	-406,312,291
February	355,969,742	-360,922,867
March	419,296,048	-377,686,769
April	381,711,250	-386,831,798
May	439,197,421	-439,590,675

Month	Sum of Volume into Quoich (m³)	Sum of Volume out of Quoich (m³)
June	318,024,226	-320,007,375
July	425,949,392	-421,724,950
August	420,915,585	-425,829,615
September	408,933,827	-435,820,626
October	410,392,654	-410,727,271
November	417,797,569	-396,828,808
December	409,813,627	-407,556,283

The predicted time series includes both pumping and generation cycles, with associated volumetric flow rates into and out of Loch Quoich based on the specific scheme arrangement and pump-turbine parameters. These flows were applied as time-varying boundary conditions within the TUFLOW FV model to simulate the dynamic thermal response of the loch to PSH operations. Specifically, this is the 2034 modelled year of January to December 2034 modelled months were used for the 2022 simulation.

A desktop study previously undertaken by Mott MacDonald (and relevant extract provided in Appendix B) was reviewed to inform the thermal characterisation of the PSH discharge. Section 6.4 of that study provides a theoretical estimate of water temperature increase per operational cycle, derived from energy loss calculations through the system. The estimated temperature rise of 0.063°C per cycle offers a scientifically grounded, albeit simplified, basis for thermal input assumptions.

To account for uncertainty and to test model sensitivity, a range of temperature increase scenarios were applied to the PSH discharge, including:

- 0.5%;
- 1%; and
- 0.063°C absolute increase.

On average a 0.063°C absolute increase is expected to increase temperatures between 0.5% and 1% for a 12-month period. However, peak increases are expected to be greater for the 0.5% and 1% across the 12-month period, specifically for warmer periods. As such the range of selected temperature increase scenarios provide the necessary variability to understand the impact to Loch Quoich.

These scenarios were used to evaluate the potential extent of thermal plume development and its influence on stratification and downstream temperatures. While the calculated increase of 0.063°C is lower than the 1% scenario, it was included to assess whether even minimal thermal inputs could result in detectable changes at the dam outtake and in the Gearr Garry.

The temperatures were extracted from the respective baseline scenarios at the location of the PSH scheme inflow/outflow points and assigned to the flow rates discussed above. This provided a relative increase to the baseline model for the comparison in determining potential impacts. Temperatures were extracted from the top vertical layer of the model (or depth averaged for 2D) and reapplied in the same vertical layer. This is discussed further in Section 3.0.

The location of the PSH Scheme inflow/outflow points within the model have been provided in Figure 2-5 and development plans provided in Appendix C (specifically the “*Lower Quoich Reservoir Plan - Figure 2.10*”).

2.2.3 Existing Quoich Hydro Discharge Rates

The outtake from Loch Quoich is controlled via two bottom draw outlet structures (through the dam and into the tunnel). The recorded operational data for the dam was used to define the outflow boundary condition in the model. This included the dams natural outtake structure as well as the Quoich power station generation flows. These outtake rates were applied as a combined time-varying discharge at the base of the dam, consistent with the physical configuration of the outlet. This approach ensures that the model accurately captures the thermal signature of water released downstream into the Gearr Garry.

The rates of the dam operations were calculated to be equivalent to a constant 13 m^3/s, and locality has been provided in Figure 2-5.

2.2.4 Meteorological Data

As well as hydrodynamic boundary conditions, the TUFLOW FV model requires meteorological data, required for atmospheric exchange and to drive surface heat exchange processes. This was obtained from the European Centre for Medium-Range Weather Forecast ERA5 reanalysis version 5 dataset. The data for the two selected simulation periods was available at hourly intervals and utilised by the model are: -

- Wind speed and direction at a height of 10m (m/s);
- Mean Sea Level Pressure (hPa.);
- Long Wave Radiation (W/m^2);
- Shortwave Radiation (W/m^2); and
- Air Temperature (ºC).

The Air Temperature data obtained from the ERA5 (shown in Figure 2-2) was processed into time-series to feed into the TUFLOW FV model and is shown in Figure 2-3, with a clear seasonal pattern.

Figure 2-2: Copernicus ERA5 Data Coverage, in this case Air Temperature

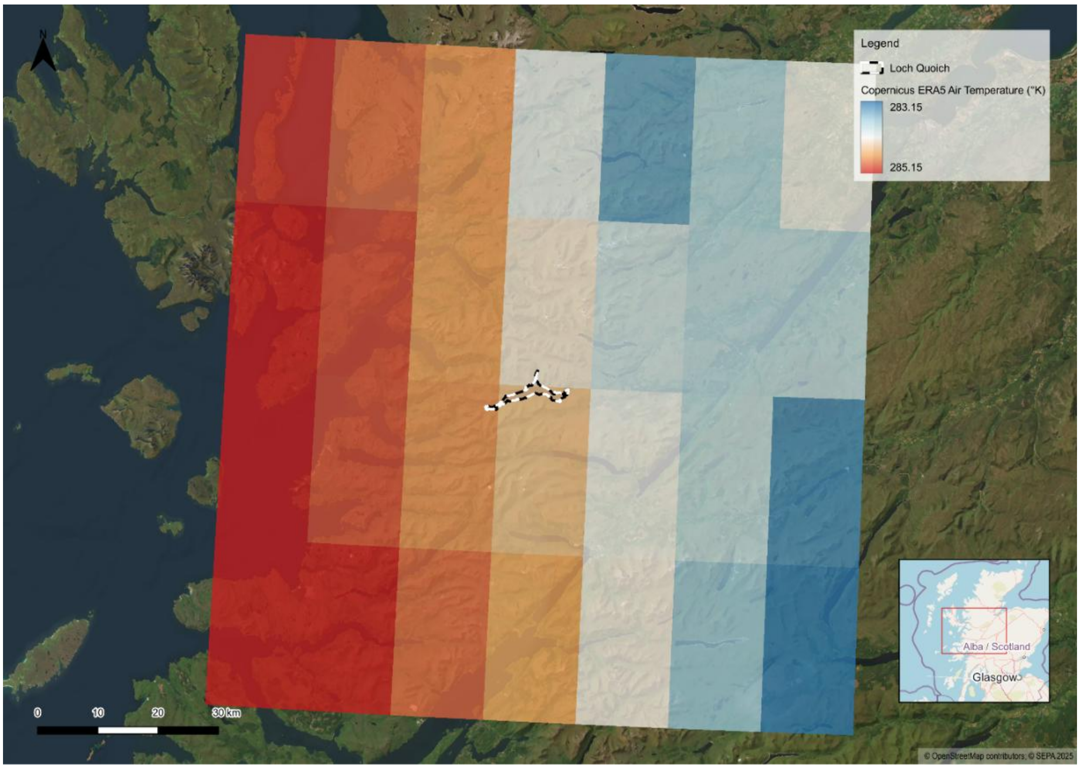


Figure 2-3: Copernicus ERA 5 Air Temperature for Loch Quoich 1st January 2022 to 1st January 2023

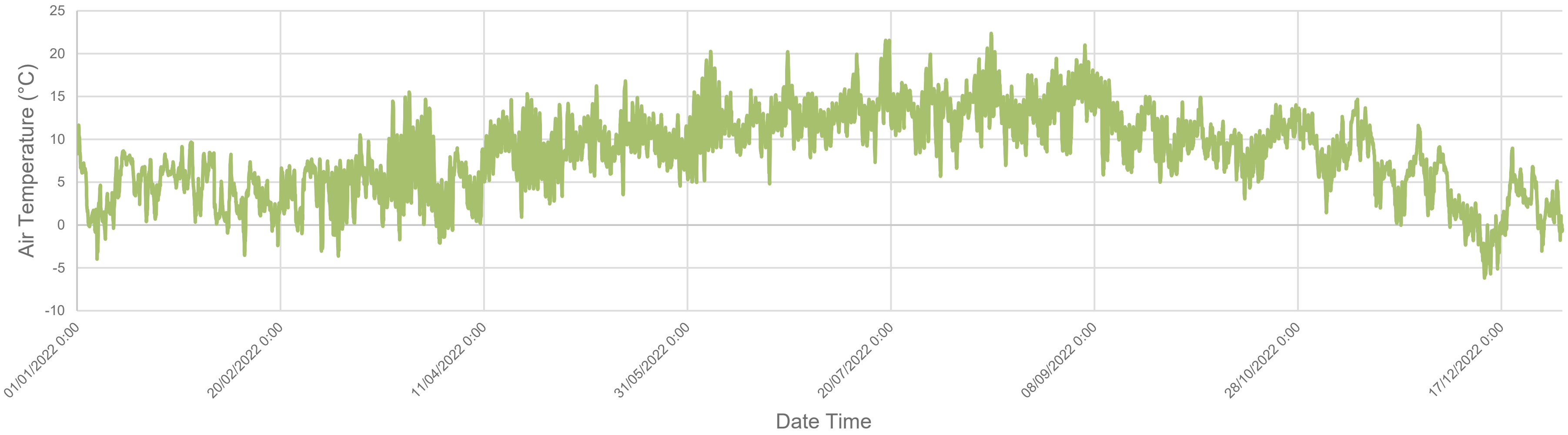
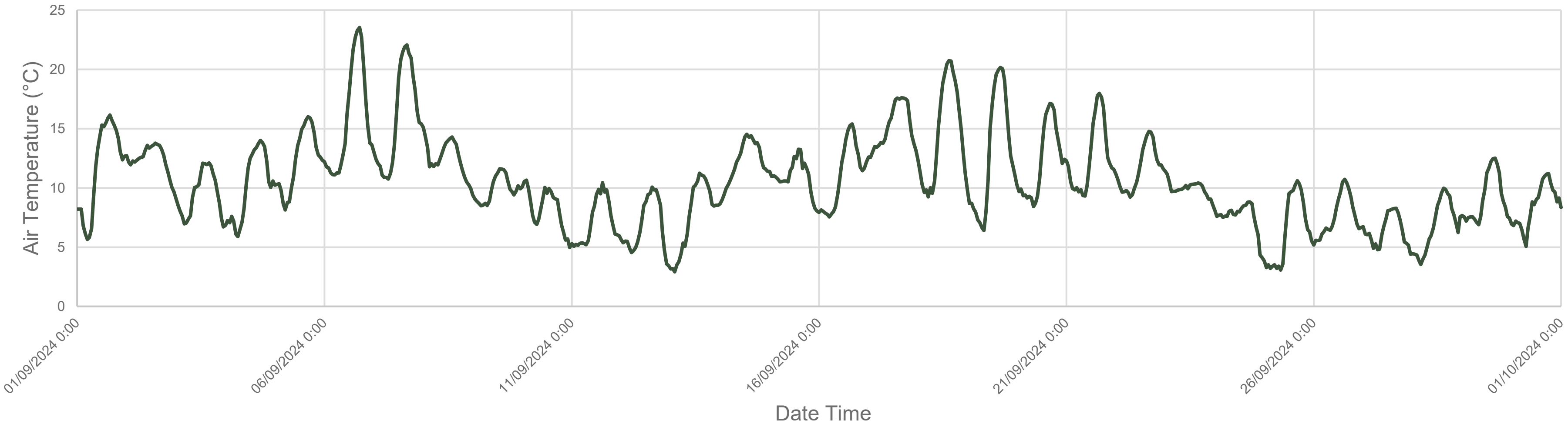


Figure 2-4: Copernicus ERA 5 Air Temperature for Loch Quoich 1st September 2024 to 30th September 2024



2.3 Modelling

The hydrodynamic and water quality modelling was undertaken using TUFLOW FV (version 2025.1.0). The software simulated both the flow movement and the thermal mixing.

2.3.1 Model Domain and Topography

The model domain encompasses the full extent of Loch Quoich, from its upstream inflows to the dam at the downstream end. The domain was defined using available bathymetric survey data, which provided detailed depth information across the loch. The vertical layering of the model was configured to allow for higher resolution in the upper water column, where thermal gradients are most pronounced during stratification periods. The model terminates at the dam, which serves as the downstream boundary for hydrodynamic and thermal exchange.

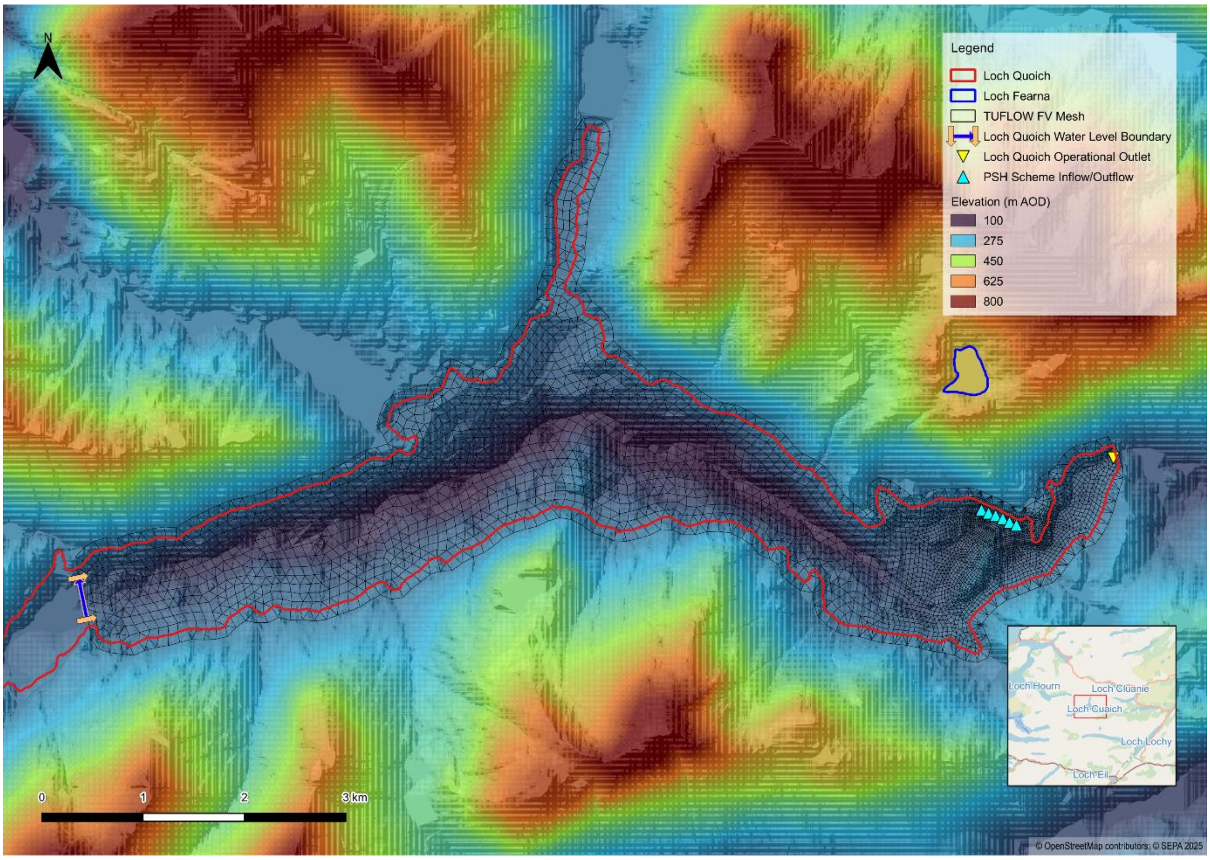
2.3.2 Mesh Development and Hydraulic Parameters

A 2D mesh was completed using SMS software (v13.2):

- The 2D mesh was refined near the discharge point and model boundaries
- A uniform Manning's n value of 0.035 was used across the model domain, suitable for a loch with no floodplain interaction.

The 2D mesh and bathymetry is shown in Figure 2-5.

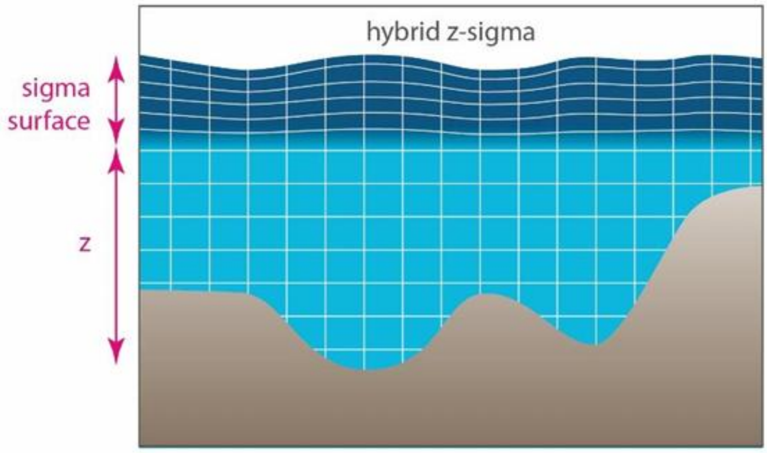
Figure 2-5: TUFLOW FV Bathymetry Mesh and Hydrodynamic Inflow/Outflow Points



2.3.3 3D Model Methodology

The 3D model was configured using mixed sigma-layer (top of water column) and fixed elevation (bottom) vertical discretisation to resolve vertical temperature gradients and stratification processes. A vertical cell depth of 10 meters was selected. An example of mixed sigma-layer (“hybrid z-sigma”) vertical discretisation has been extracted from the TUFLOW FV Manual[2] and provided in Figure 2-6 below.

Figure 2-6: Hybrid Z-Sigma 3D Model Vertical Discretisation



The model also incorporated temperature-dependent density variations to simulate buoyancy-driven circulation and vertical mixing. Turbulence closure was handled using a k-epsilon (k-ε) scheme, which is suitable for stratified lake environments.

Initial conditions for the one-month (September 2024) period were defined using observed water temperature profiles from Loch Quoich, ensuring that the model started from a realistic thermal state. The initial depth vs temperature values have been provided in Table 2-3. Calibration\Validation was performed over the one-month period using observed temperature data to validate the model’s ability to reproduce stratification and mixing dynamics and discussed in Section 3.1.2.

Table 2-3: 2024 Initial Water Temperature vs Depth Values

Depth (m)	Temperature (°C)
0	12.87
26	12.22
53	7.46
>53	7

Initial conditions for the 12-month (January 2022 to December 2022) period were defined assuming a single set temperature (i.e. no thermal stratification) due to the winter temperatures and expected vertical mixing for this time of year. This was set at 4.5°C and based on air temperature data supplied in Section 2.2.4 above, assumed winter water temperatures, and model results during the development of this modelling study (i.e. restart files). The initial depth vs temperature values have been provided in Table 2-4.

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[2] TUFLOW FV USER Manual – Build 2019.01
https://downloads.tuflow.com/TUFLOWFV/Releases/Latest/TUFLOW_FV_User_Manual.pdf

Table 2-4: 2022 Initial Water Temperature vs Depth Values

Depth (m)	Temperature (°C)
0	4.5
26	4.5
53	4.5
>53	4.5

3.0 Results

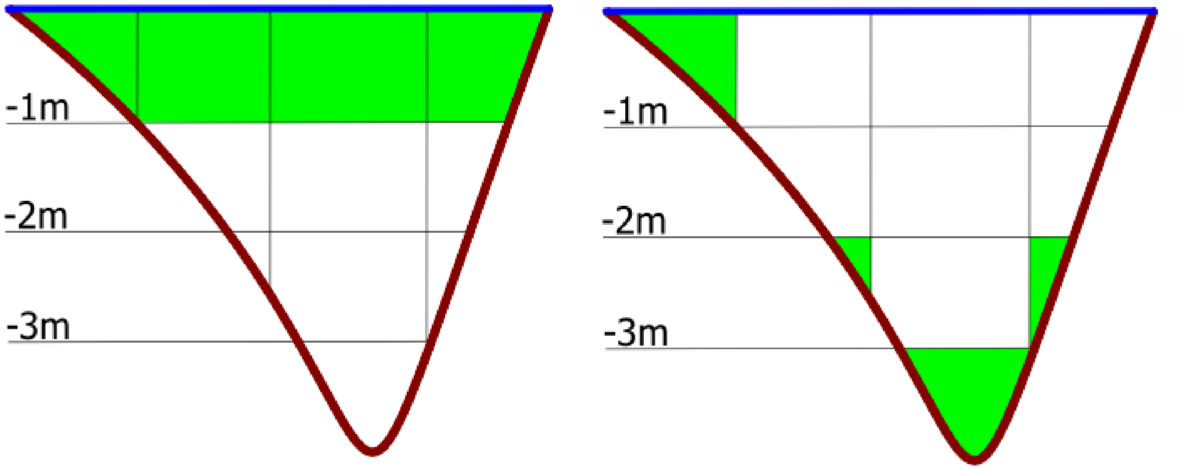
The results of the TUFLOW FV simulations are presented below, structured by scenario and operational condition. Each simulation was analysed using the 3D (vertical profile) outputs to assess the thermal structure of Loch Quoich and the influence of the PSH scheme.

3D results were assessed based on three main approaches. These were:

- The value at the bottom vertical layer, important for understanding temperature extraction from the operational outlet into Gearr Garry;
- The value at the top vertical layer, important for inflow and outflow of PSH locations; and
- Curtain plots (longitudinal or cross-sectional), showing the vertical distribution of model outputs (and potential thermal stratification).

The "top vertical layer" displays the value from the surface level cell. The "bottom vertical layer" displays the value from the bed level cell. In each state, the interrogated level is truncated to the maximum number of vertical layers for a particular face. An example of this is provided below in Figure 3-1.

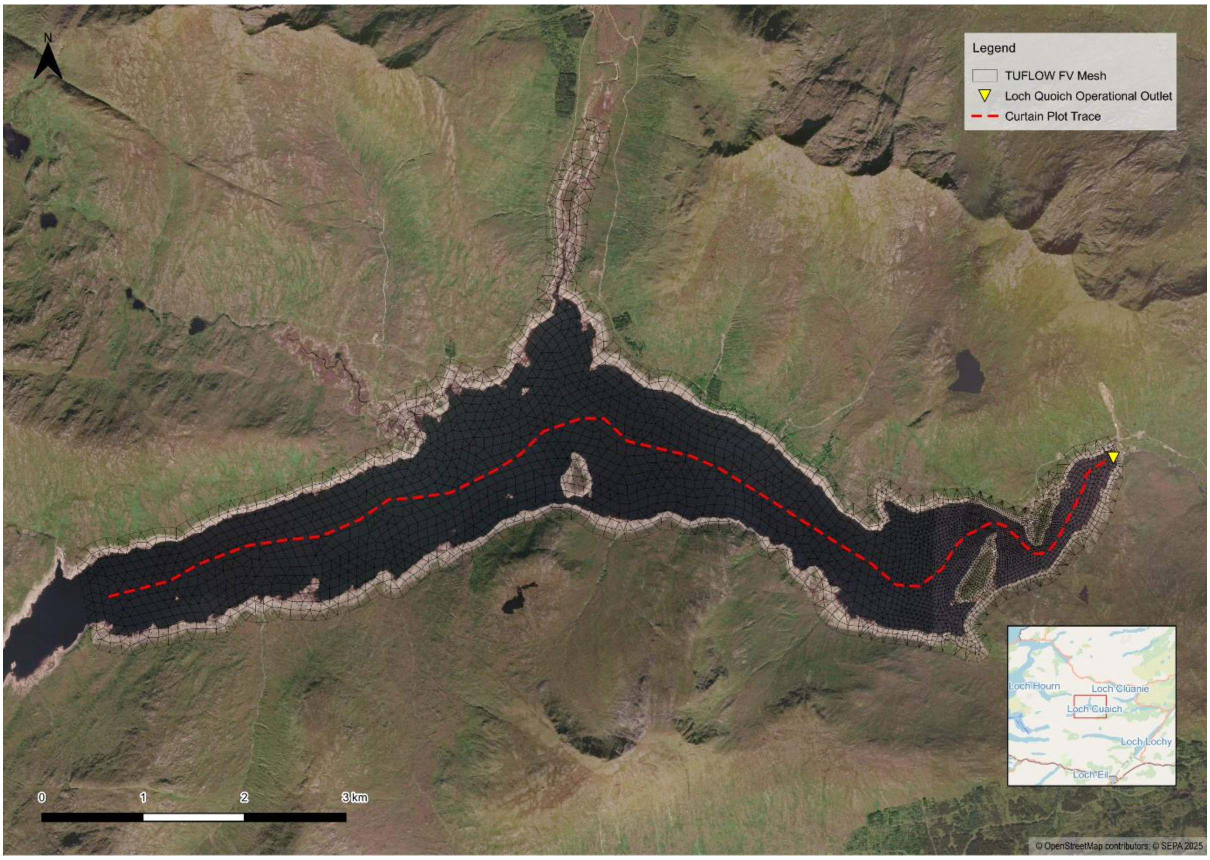
Figure 3-1: 3D Result Interrogation Methods



Curtain plots were all extracted for the model results based on the upstream inflow location to Loch Quoich, down to the operational outtake at the Dam wall. A curtain plot is a type of 2D visualization used in environmental and hydrodynamic modelling to show how a variable (temperature in this case) changes with depth and along a horizontal transect. The trace chainage of the curtain plots discussed in this section has been provided in Figure 3-2.

Along with each curtain plot is the depth averaged 3D results showing the average temperature for the water column. Depth-averaged results provide a valuable overview in 3D hydrodynamic studies, making it easier to identify areas where colder water may persist below the thermocline. When viewed in plan, these results help highlight spatial patterns of thermal stratification, offering a practical means of interpreting complex vertical temperature structures across the domain.

Figure 3-2: 3D Result Curtain Plot Locations



© OpenStreetMap contributors; © SEPA 2025

3.1 September 2024 1-Month Simulation

3.1.1 Baseline Conditions

Baseline modelling results indicate that Loch Quoich exhibited thermal stratification throughout the September 2024 simulation period. The 3D model outputs were analysed using top and bottom vertical layers, as well as curtain plots along the longitudinal trace from the modelled inflow to the dam wall.

3.1.1.1 Thermal Structure and Stratification

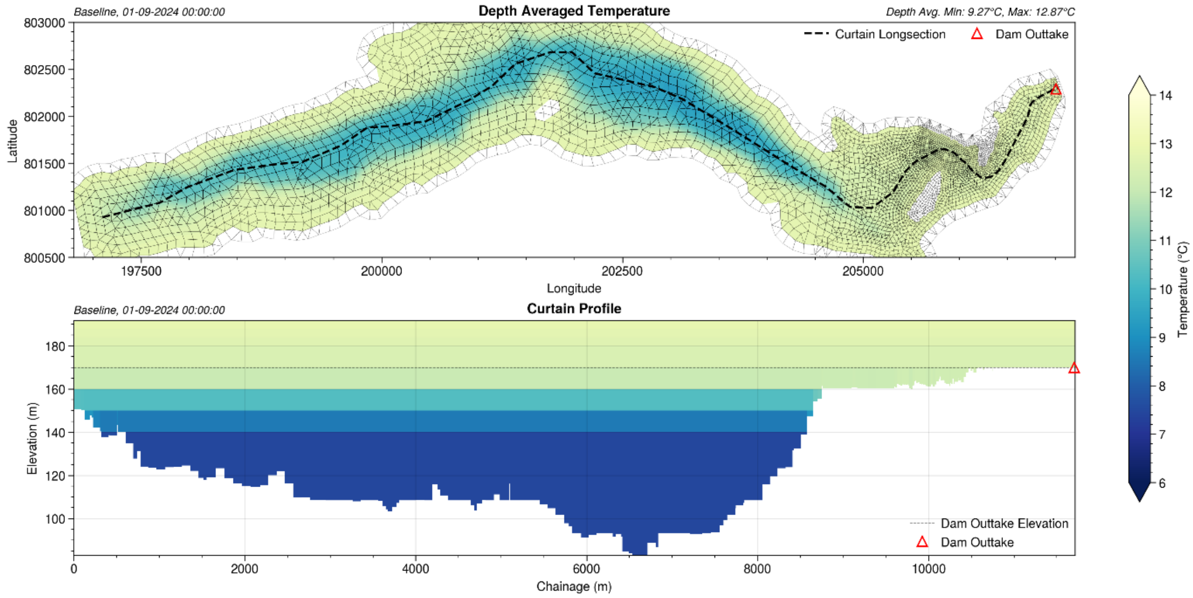
A well-defined thermocline developed between approximately 30m and 60m depth, separating the warmer surface layer from the cooler hypolimnion. Surface temperatures (top vertical layer) remained below 13°C throughout the simulation, fluctuating between 13°C at the warmer start of the month, to 10°C at the end of the month, with clear, however minor, diurnal variability. Bottom temperatures (bottom vertical layer) were more stable, at the deepest location of the loch ranging from 7°C at the start of the simulation to 8°C at the end of the simulation, indicating vertical mixing is occurring however thermal inertia is still pertinent.

The dam outtake, which draws from the bottom layer, extracted cooler water at some parts the simulation, relevant for assessing downstream impacts on the Gearr Garry.

3.1.1.2 Curtain Plot Analysis

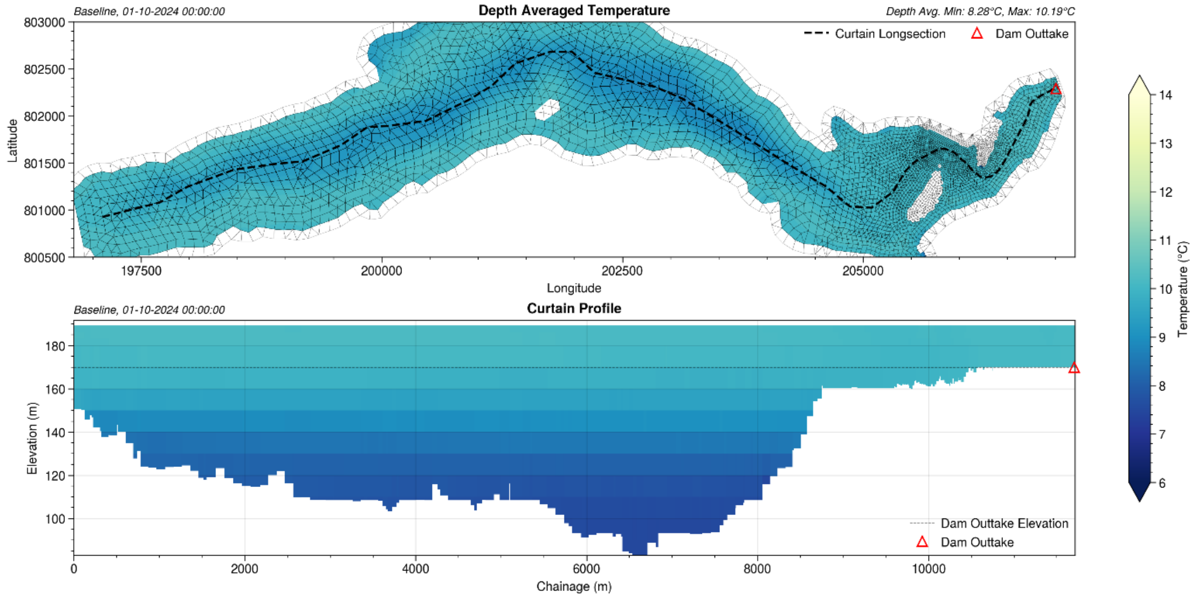
The curtain plot at the start of the simulation (01/09/2024) shows a strongly stratified profile, with a sharp temperature gradient between the surface and bottom layers, as expected from the initial conditions set. The thermocline is clearly visible and stable across the traced chainage. This is shown in Figure 3-3.

Figure 3-3: Curtain Plot of Temperature Profile Along Longitudinal Trace (Baseline 2024 at time 01/09/2024 00:00:00)



By the end of the simulation (01/10/2024), the thermocline had weakened slightly, with surface cooling and a broader transition zone. This suggests the early stages of autumnal turnover, though stratification remained largely intact. This is shown in Figure 3-4.

Figure 3-4: Curtain Plot of Temperature Profile Along Longitudinal Trace (Baseline 2024 at time 01/10/2024 00:00:00)



3.1.1.3 Vertical Profile at Dam Outtake

The time series of temperature at the dam outtake shows a persistent temperature difference between the top and bottom layers throughout the month.

Surface temperatures (top vertical layer) remained consistently warmer than bottom temperatures, except during two brief periods, 11/09/2024 to 16/09/2024 and 26/09/2024 to 01/10/2024, when the two layers closely matched. These events may indicate short-term vertical mixing or reduced stratification strength. Depths at this location are also smaller allowing diurnal variability to slightly impact the bottom vertical layer during the weeks of highest mixing.

The periods of highest water temperature differences align well with the highest air temperatures for the simulation period indicating the clear atmospheric impact at this location.

The vertical profile plot at the dam outtake is provided in Figure 3-5.

Figure 3-5: Vertical Temperature Profile at Dam Outtake (Baseline 2024)

3.1.2 Validation Against Monitored Data

Model outputs were validated against observed temperature data collected at multiple sampling locations within Loch Quoich during the September 2024 simulation period. The monitoring data was obtained from the Environmental Impact Assessment (EIA) report prepared by Gilkes Energy in February 2025 (see Appendix D).

Figure 3-6: Map of sampling locations used for validation

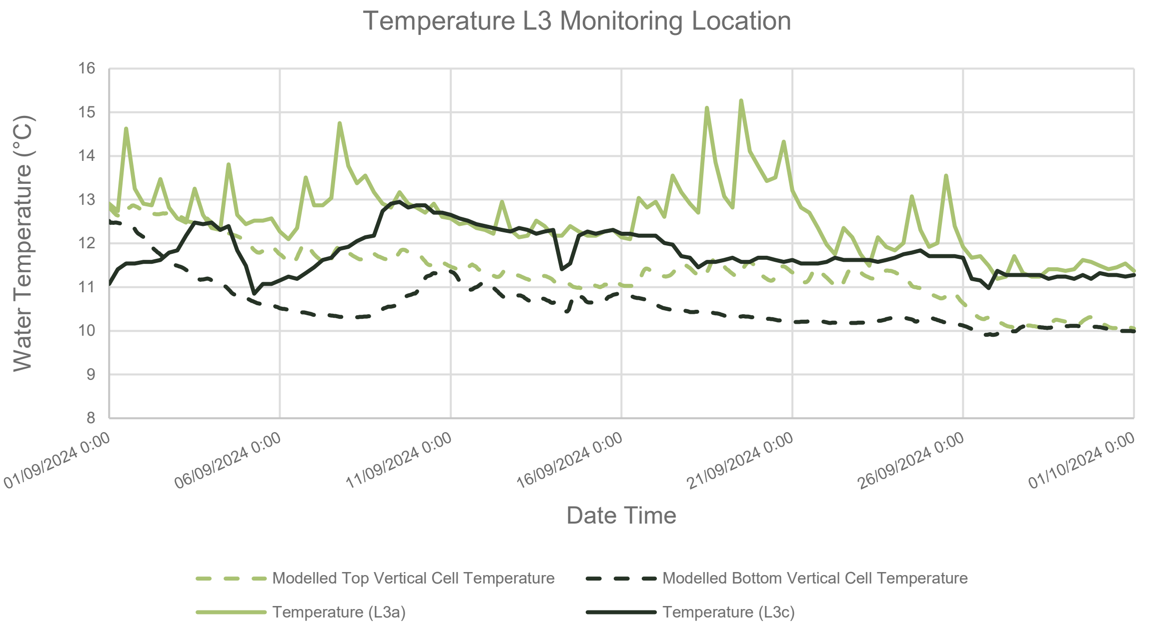
Validation was performed using data from Monitoring Locations L3 and L4, which provided both surface and bottom temperature measurements. These were compared against the modelled top and bottom vertical cell temperatures at the corresponding locations.

3.1.2.1 Temperature Validation at Location L3

The modelled temperatures do not perfectly match the observed values; however, the overall trends align well. Both modelled and measured data show synchronous temperature behaviour, with surface and bottom temperatures converging at similar times. Measured temperatures exhibit sharper spikes, particularly in the surface layer, which are not fully captured by the model. This is attributed to the vertical resolution of the model, with each cell at approximately 10m deep (and slight cell depth variability in the surface layer cell), which smooths out short-term fluctuations. Despite this, diurnal temperature variation is present in the modelled results, indicating that atmospheric exchange is being accurately simulated.

L3 Monitoring and model extracted top and bottom temperatures are provided in Figure 3-7.

Figure 3-7: Temperature L3 Monitoring Location Validation



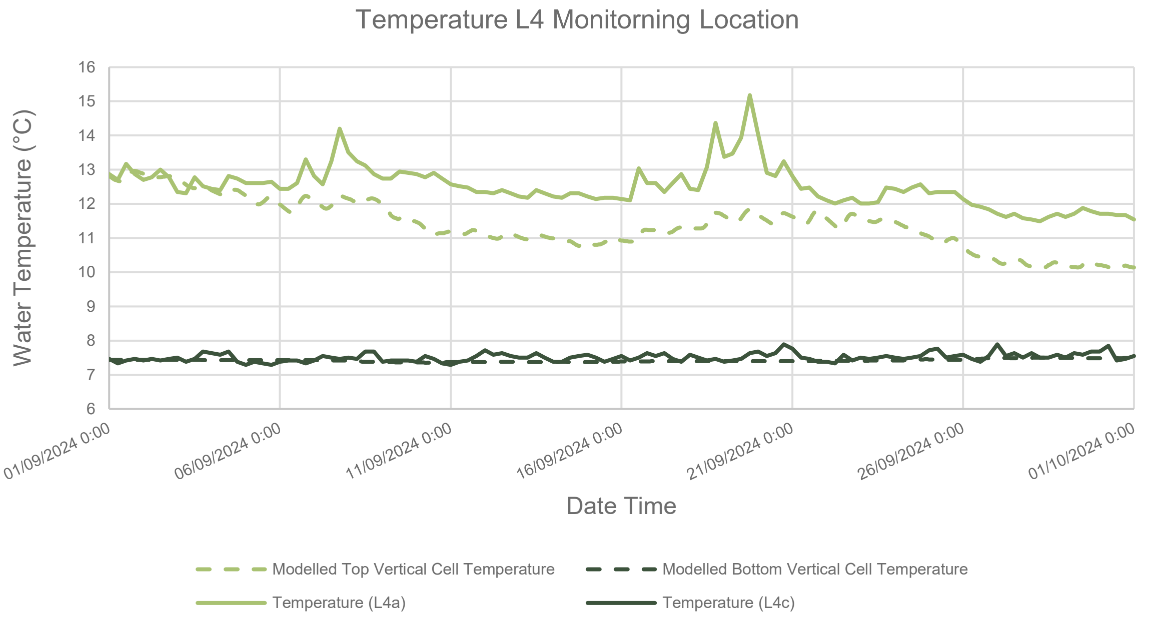
3.1.2.2 Temperature Validation at Location L4

The bottom temperature match is nearly perfect, with modelled and measured values closely aligned throughout the simulation period. Surface temperatures again show trend alignment, with smaller spikes in the measured data occurring at the same times as fluctuations in the modelled results.

As with Location L3, the modelled surface temperatures are smoother, due to the vertical cell depth, but still capture the diurnal variability observed in the field data.

L4 Monitoring and model extracted top and bottom temperatures are provided in Figure 3-8.

Figure 3-8: Temperature L4 Monitoring Location Validation



3.1.2.3 Summary of Validation Results

The summarised values presented in Table 3-1 and Table 3-2 have been taken from the final timestep of the simulation. This approach ensures that all model processes, such as thermal stratification, atmospheric exchange, and hydrodynamic adjustment, have had sufficient time to stabilise, providing a more accurate representation of model performance for validation purposes.

Table 3-1: Observed vs Modelled Surface Temperatures (°C)

Location	Observed	Modelled	Difference
L3	11.4	10.1	-1.3
L4	11.5	10.1	-1.4

Table 3-2: Observed vs Modelled Bottom Temperatures (°C)

Location	Observed	Modelled	Difference
L3	11.3	10.0	-1.3
L4	7.5	7.5	0

Overall, the model demonstrated good agreement with observed data. The strongest alignment was observed in the bottom layers, particularly at Location L4. Minor deviations in surface temperatures are attributed to the model's vertical resolution and smoothing of short-term thermal spikes.

3.2 2022 12-Month Simulation

3.2.1 Baseline Conditions

Baseline modelling results indicate that Loch Quoich exhibited thermal stratification throughout the 2022 simulation period. The 3D model outputs were analysed using top and bottom vertical layers, as well as curtain plots along the longitudinal trace from the modelled inflow to the dam wall.

3.2.1.1 Thermal Structure and Stratification

A well-defined thermocline developed between approximately 20m and 50m depth, separating the warmer surface layer from the cooler hypolimnion. Surface temperatures (top vertical layer) began the simulation at 4.5°C and reached approximately 15°C at the end of the simulation. Clear, however minor, diurnal variability is also visible through the simulation. Bottom temperatures (bottom vertical layer) were more stable, at the deepest location of the loch ranging from 4.5°C at the start of the simulation to 6°C at the end of the simulation, indicating vertical mixing is occurring however strong thermal inertia is pertinent.

The dam outtake, which draws from the bottom layer, has a shallower depth and as such, for most of the simulation, vertical mixing proves to keep temperatures consistently similar in the water column.

3.2.1.2 Curtain Plot Analysis

The curtain plot at the start of the simulation (01/01/2022) shows a single set temperature of 4.5°C (as per the set initial conditions). This is shown in Figure 3-9.

By the middle of the simulation (01/07/2022), the thermocline had developed strongly with surface heating from corresponding seasonal air temperature increases. This suggests a strong thermal inertia, through clear thermal stratification. A temperature gradient between the surface and bottom layers of up to 9°C is visible. This is shown in Figure 3-10.

By the peak time for salmon spawning (01/11/2022 through to 30/11/2022), the thermocline had begun to weaken. The thermocline is however clearly visible and stable across the traced chainage at the start of the month, ranging from 7.3°C at the bottom of the loch to 8.3°C at the top of the loch. By the end of the month temperatures within the loch almost completely mixed, reaching a temperature of approximately 6.5°C throughout the loch. This is shown in Figure 3-11 and Figure 3-12 for the start and end of November respectively.

By the end of the simulation (01/01/2023), the temperature in the loch has completely vertically mixed and is approximately 5°C-5.5°C. Colder areas are visible particulate near shallow depths at the dam outtake and around the loch extents. This is expected as air temperatures at this time have dropped to below 0°C.

It should be noted that each plot provided has a different temperature scale due to the wide temperature range throughout the year.

3.2.1.3 Vertical Profile at Dam Outtake

The time series of temperature at the dam outtakes show a consistent temperature between the top and bottom layers throughout most of the 12 months.

Surface temperatures (top vertical layer) remained consistently similar to the bottom temperatures, specifically for the first and last 3 months of the simulation. As atmospheric temperatures began to rise, and the interaction with wind on the surface, periods of the top vertical layer began to warm. The first significant evidence of this occurs at approximately 26/03/2022, with larger variances occurring at later dates such at 02/06/2022.

As diurnal variability begins to increase in the latter half of the simulation, the results indicate trend correlation to the meteorological data.

The periods of highest water temperature differences align well with the highest air temperatures for the simulation period indicating the clear atmospheric impact at this location.

The vertical profile plot at the dam outtake is provided in Figure 3-14.

Figure 3-9: Curtain Plot of Temperature Profile Along Longitudinal Trace (Baseline 2022 at time 01/01/2022 00:00:00)

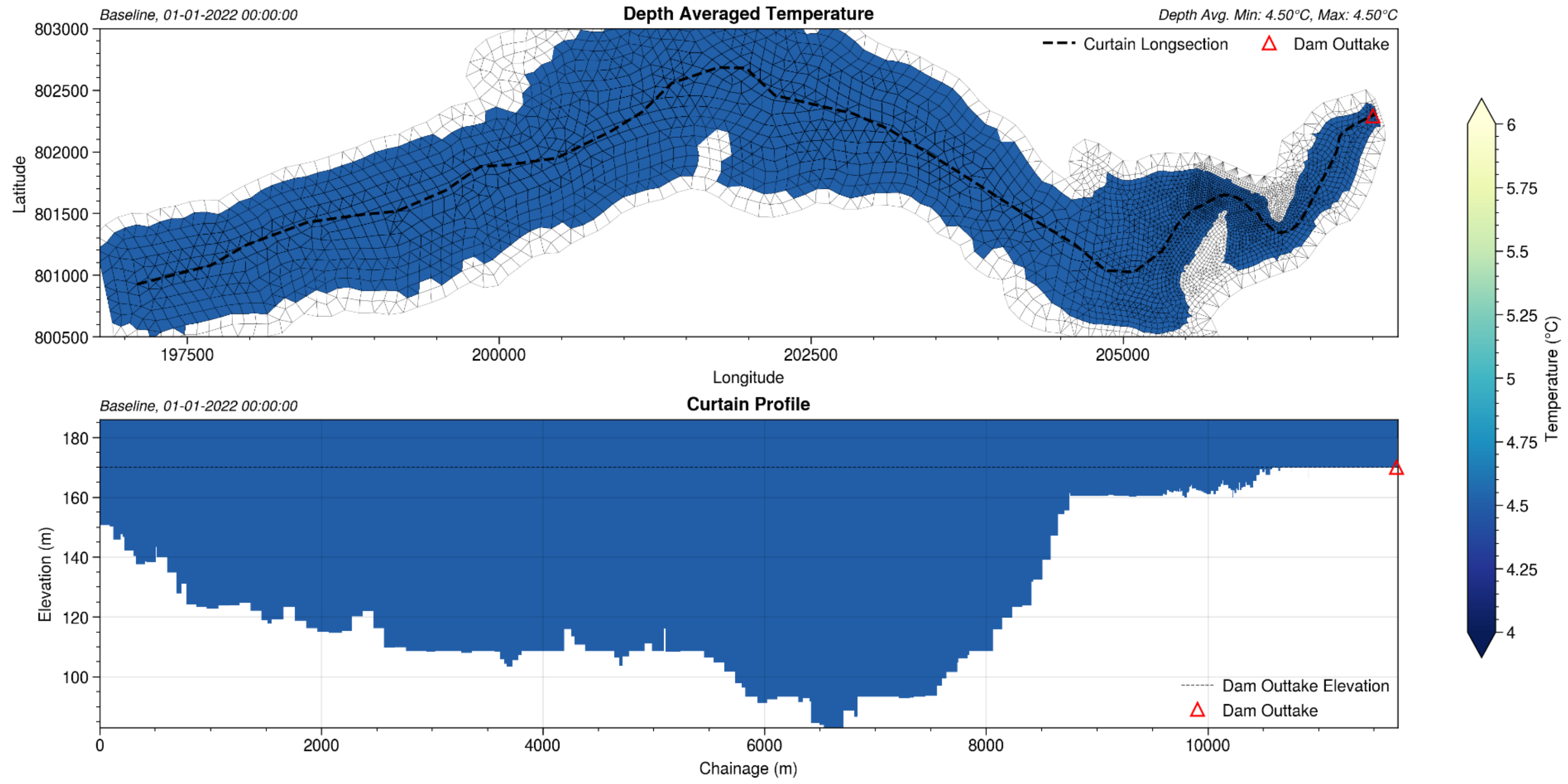


Figure 3-10: Curtain Plot of Temperature Profile Along Longitudinal Trace (Baseline 2022 at time 01/07/2022 00:00:00)

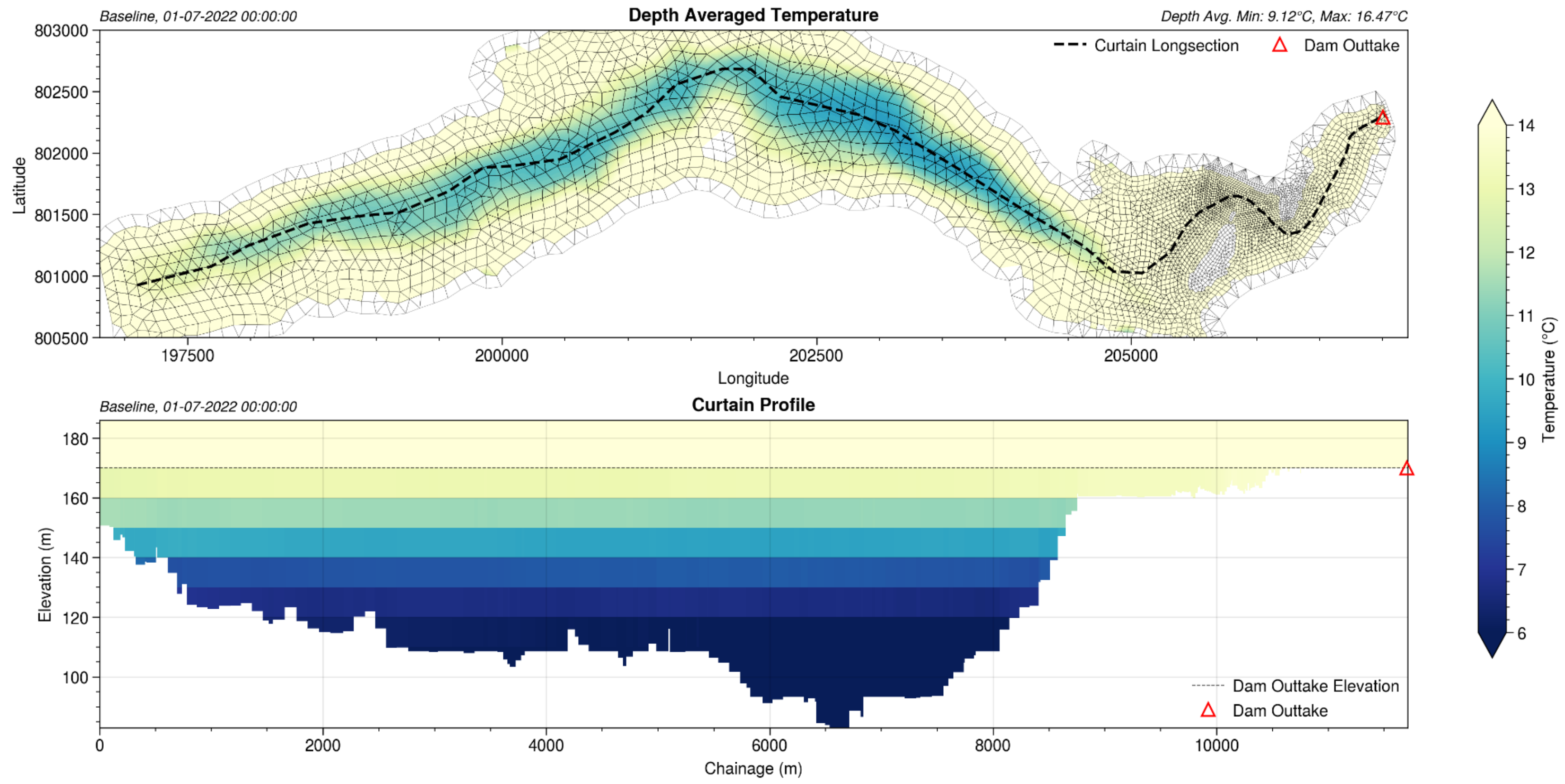


Figure 3-11: Curtain Plot of Temperature Profile Along Longitudinal Trace (Baseline 2022 at time 01/11/2022 00:00:00)

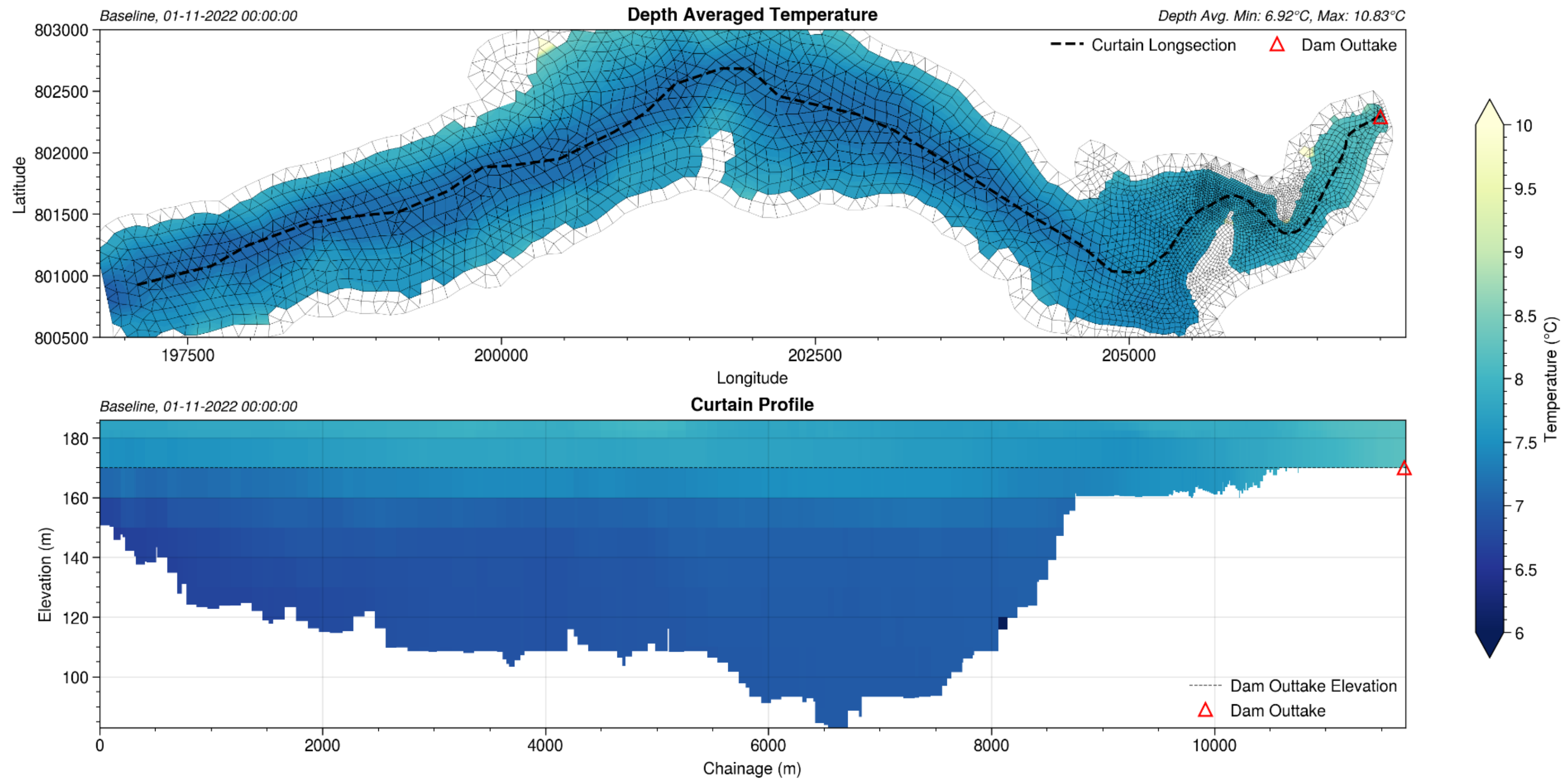


Figure 3-12: Curtain Plot of Temperature Profile Along Longitudinal Trace (Baseline 2022 at time 30/11/2022 00:00:00)

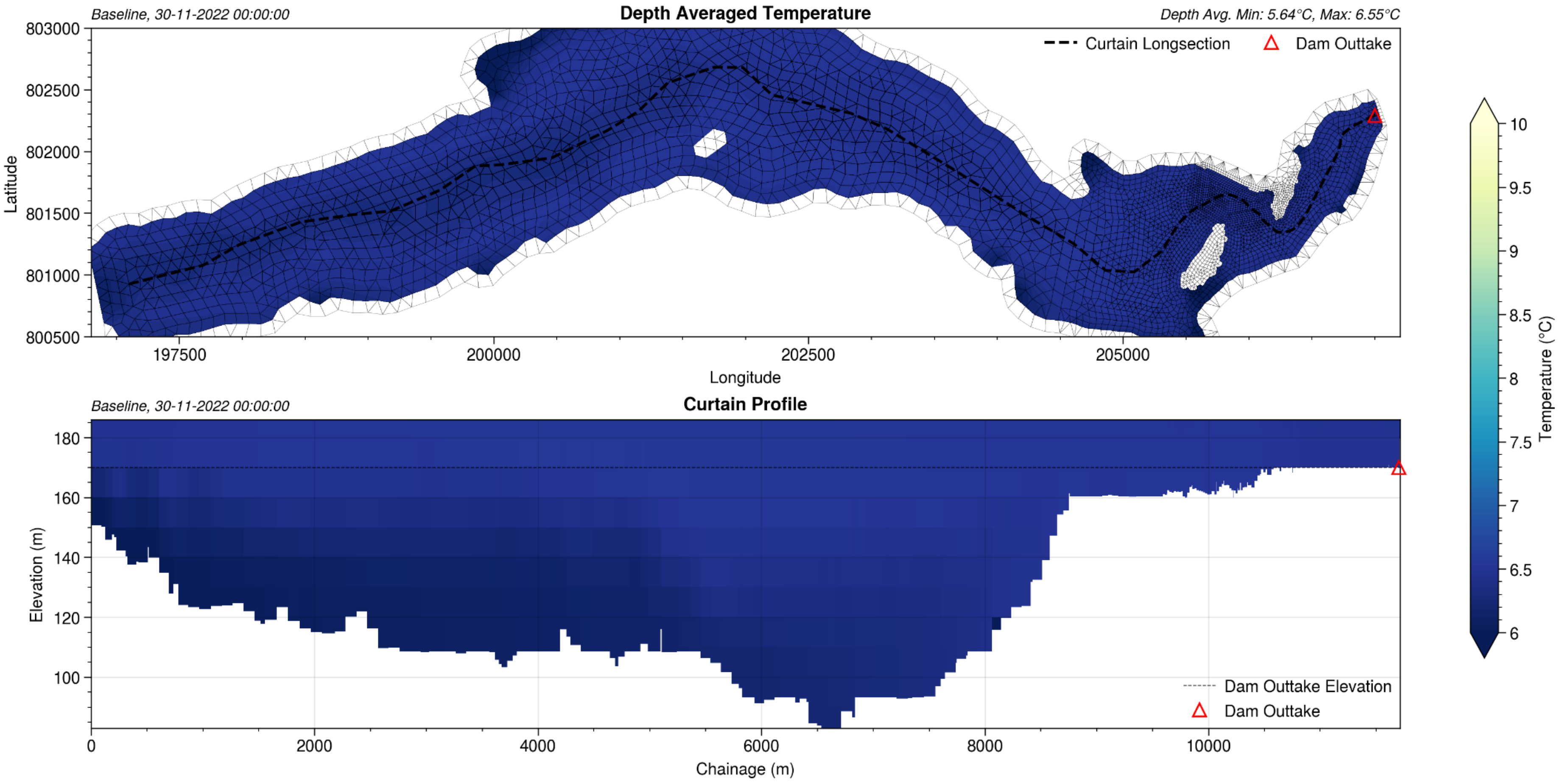


Figure 3-13: Curtain Plot of Temperature Profile Along Longitudinal Trace (Baseline 2022 at time 01/01/2023 00:00:00)

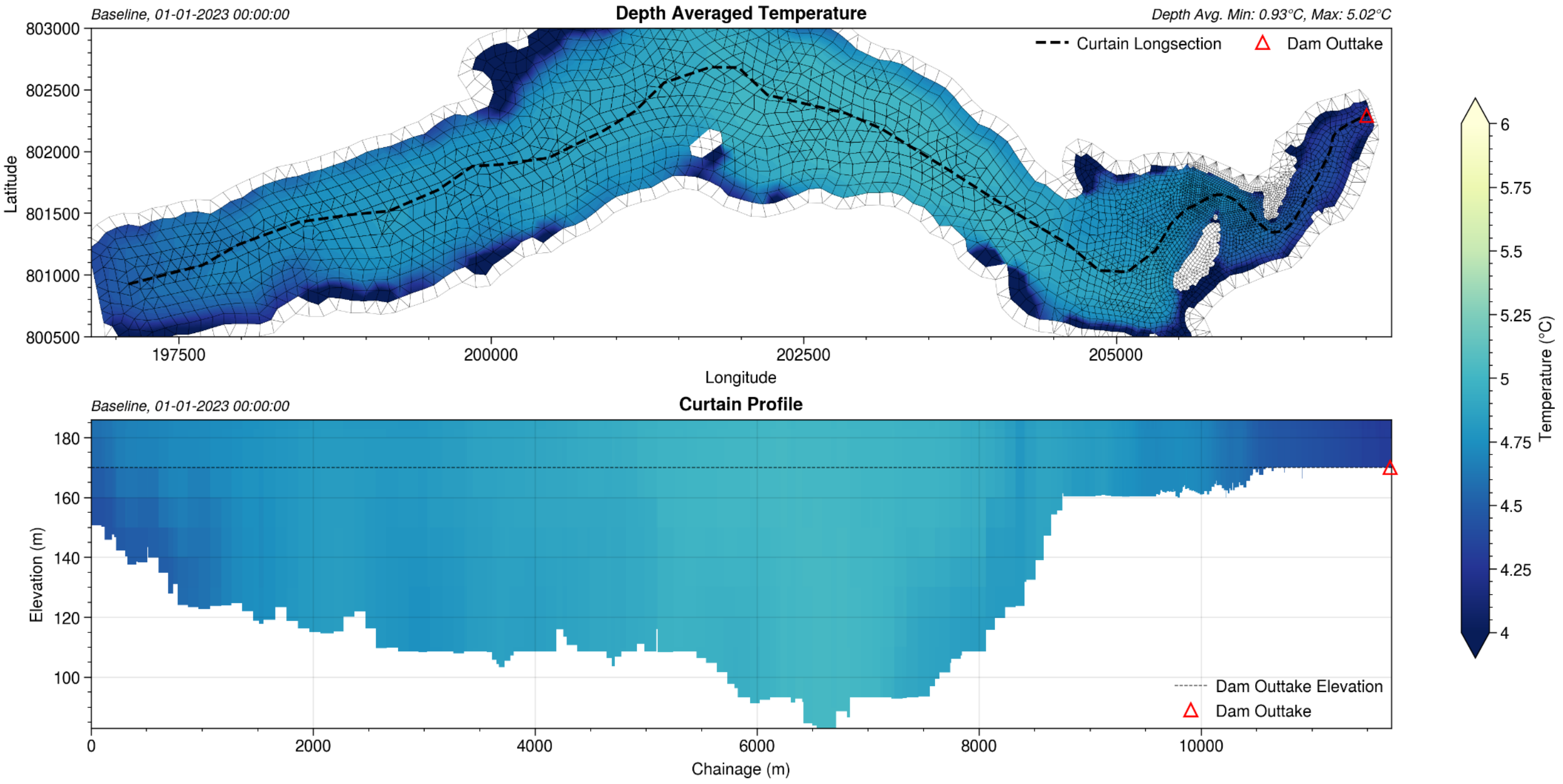
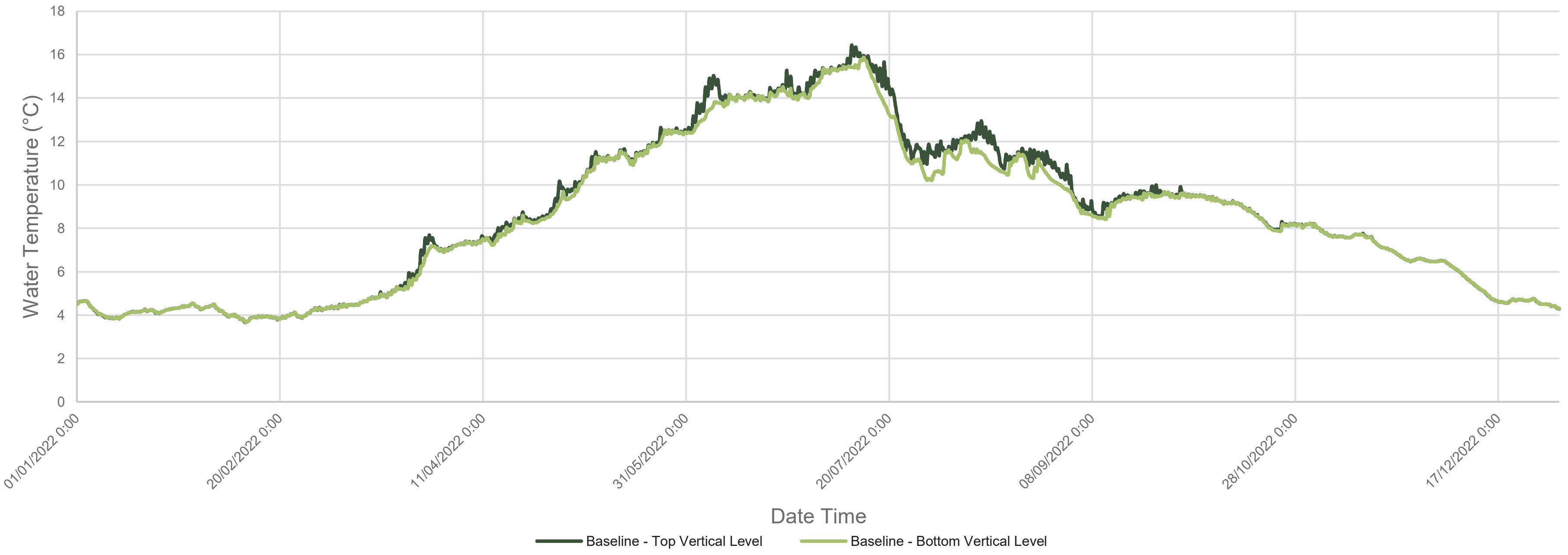


Figure 3-14: Vertical Temperature Profile at Dam Outtake (Baseline 2022)



3.2.2 PSH Operation Scenario

To assess the potential thermal impact of the Fearna PSH scheme on Loch Quoich, a series of simulations were conducted using incrementally increased discharge temperatures. These scenarios represent a range of plausible thermal inputs, from a conservative estimate based on energy loss calculations (0.063°C increase) to a worst-case assumption of a 1% temperature increase.

Figure 3-15 to Figure 3-23 show the curtain plots and the vertical temperature profile for the 0.063°C absolute temperature increase modelled scenario. With the vertical temperature plots below, accompanying difference plots showing the difference in temperature to the baseline temperature at the same timestep are also provided to give clarity on impacts of the PSH scheme on Loch Quoich at a given time.

It should be noted that the PSH sensitivity (0.5% and 1% increase in temperature) curtain plots for temperature and difference have been provided in Appendix E.

Temporal top and bottom vertical temperature plots at the dam outtake have been provided for the 0.063°C, 1% and 0.5% increase scenarios against the baseline results in Figure 3-25, Figure 3-26 and Figure 3-27 respectively.

The 2022 Baseline temperature profile, 0.063°C absolute increase temperature profile and the 0.063°C absolute increase difference curtain plot and depth averaged result animations are provided in Appendix F.

Figure 3-15: Curtain Plot of Temperature Profile Along Longitudinal Trace (PSH 0.063°C Increase at time 01/01/2022 00:00:00)

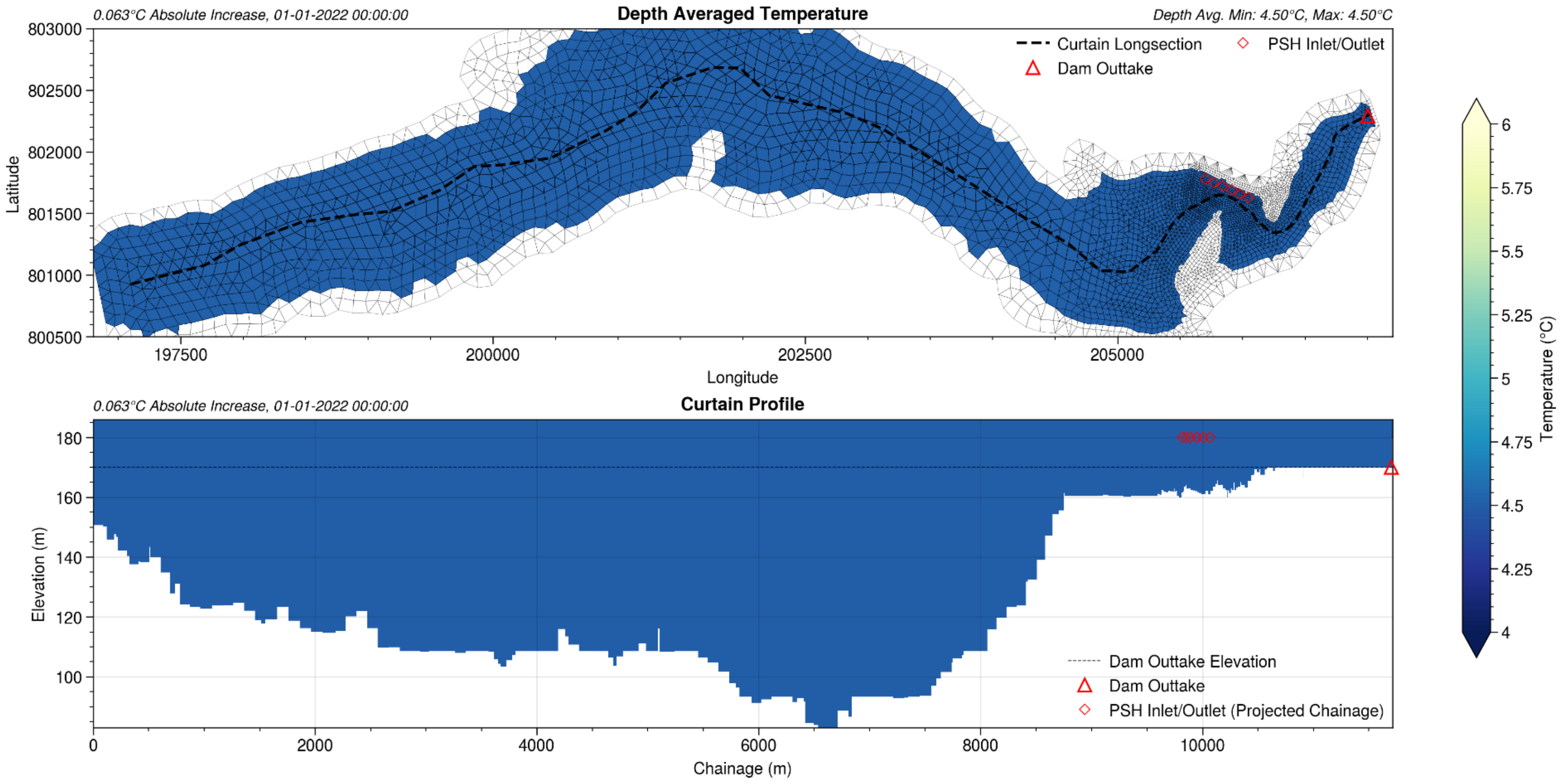


Figure 3-16: Curtain Plot of Temperature Difference Along Longitudinal Trace (PSH 0.063°C Increase at time 01/01/2022 00:00:00)

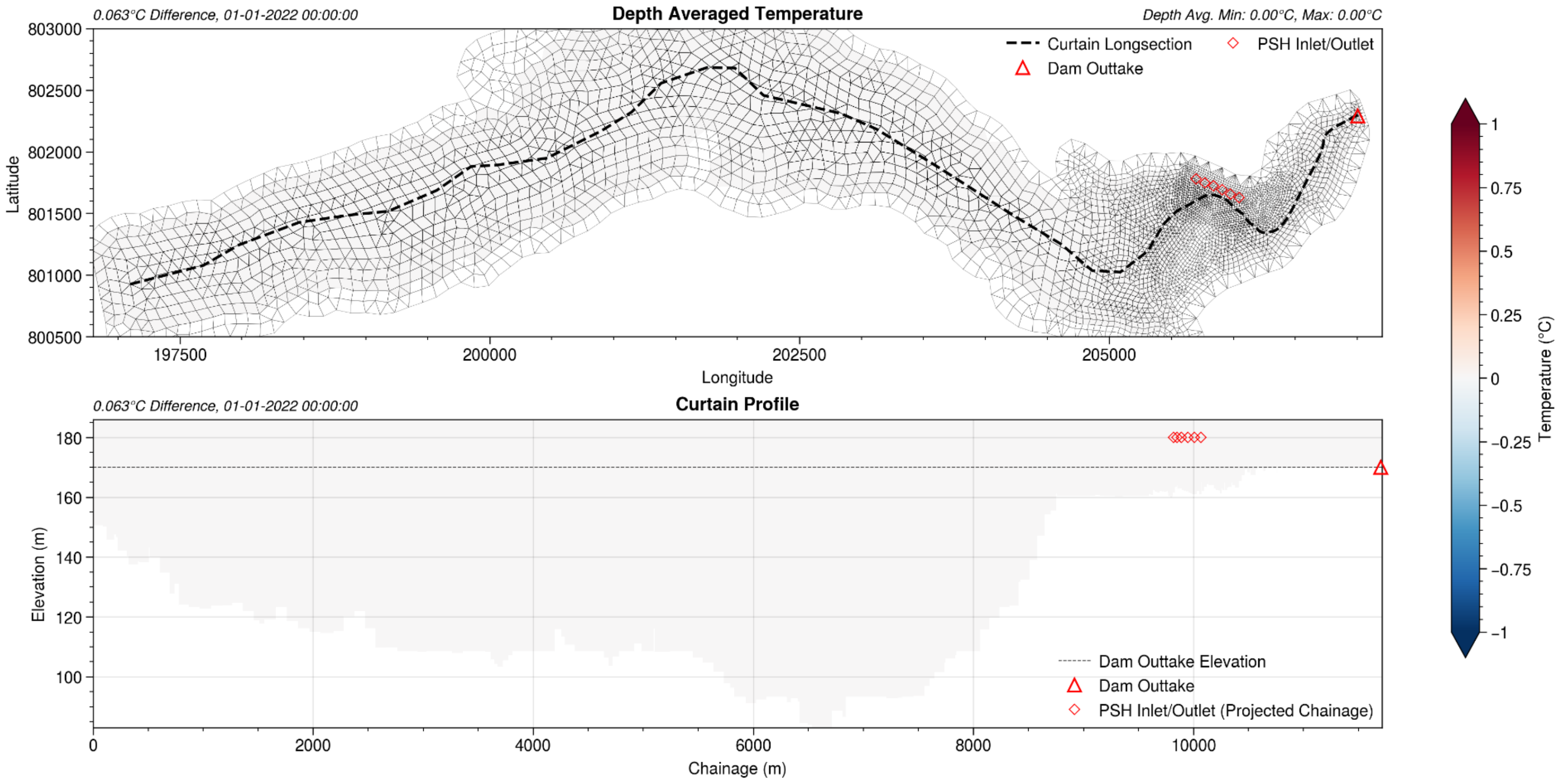


Figure 3-17: Curtain Plot of Temperature Profile Along Longitudinal Trace (PSH 0.063°C Increase at time 01/07/2022 00:00:00)

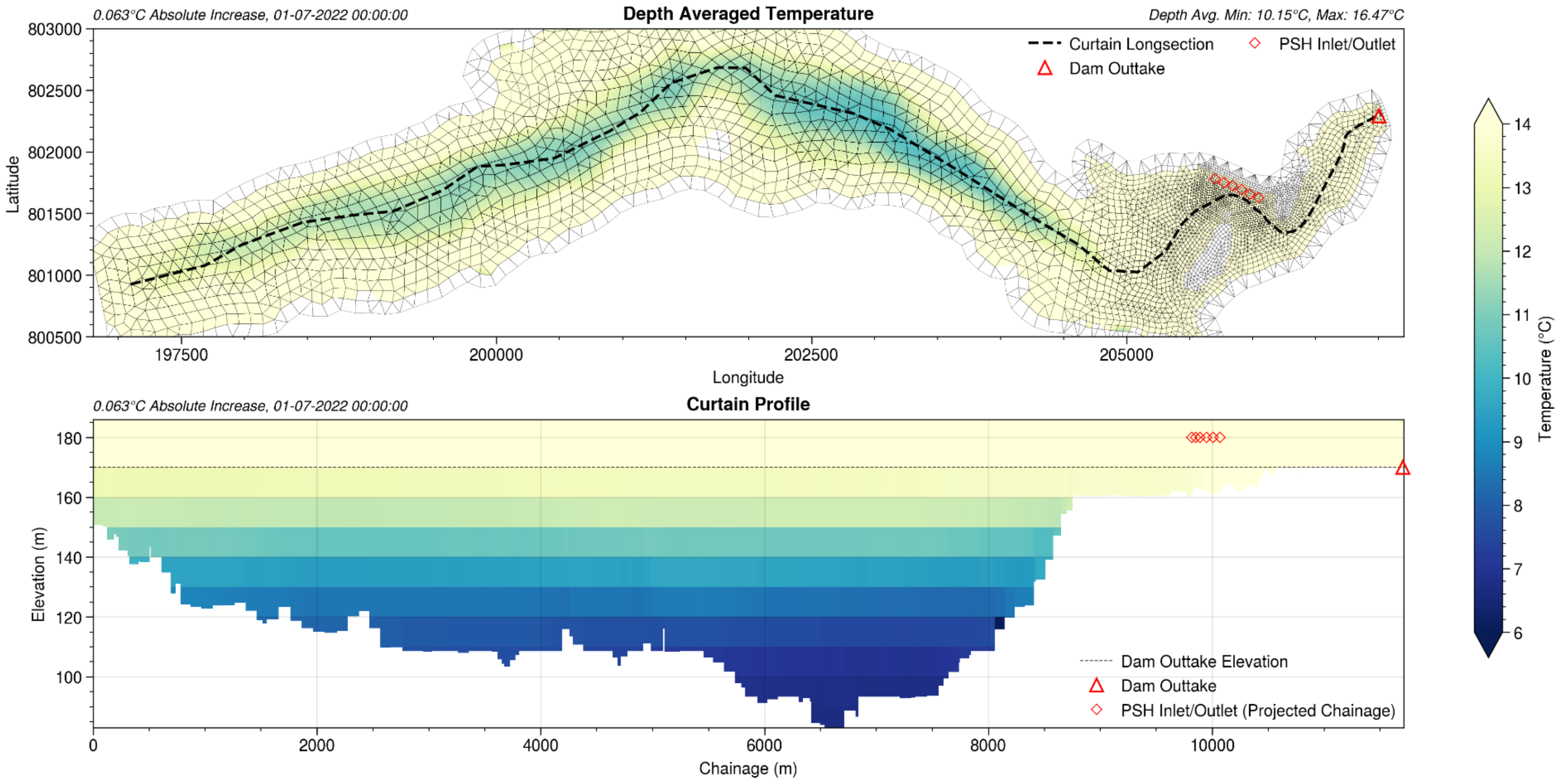


Figure 3-18: Curtain Plot of Temperature Difference Along Longitudinal Trace (PSH 0.063°C Increase at time 01/07/2022 00:00:00)

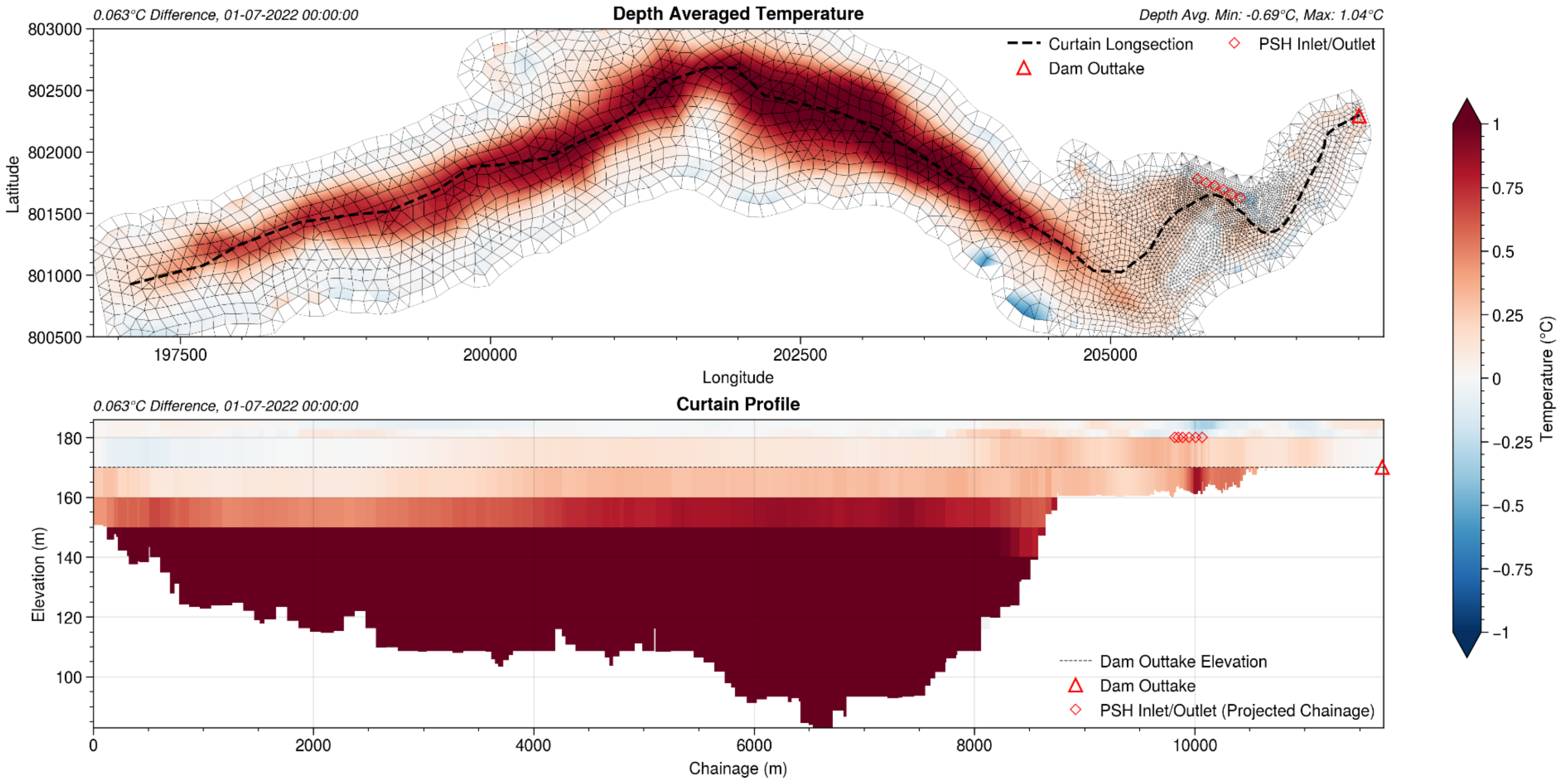


Figure 3-19: Curtain Plot of Temperature Profile Along Longitudinal Trace (PSH 0.063°C Increase at time 01/11/2022 00:00:00)

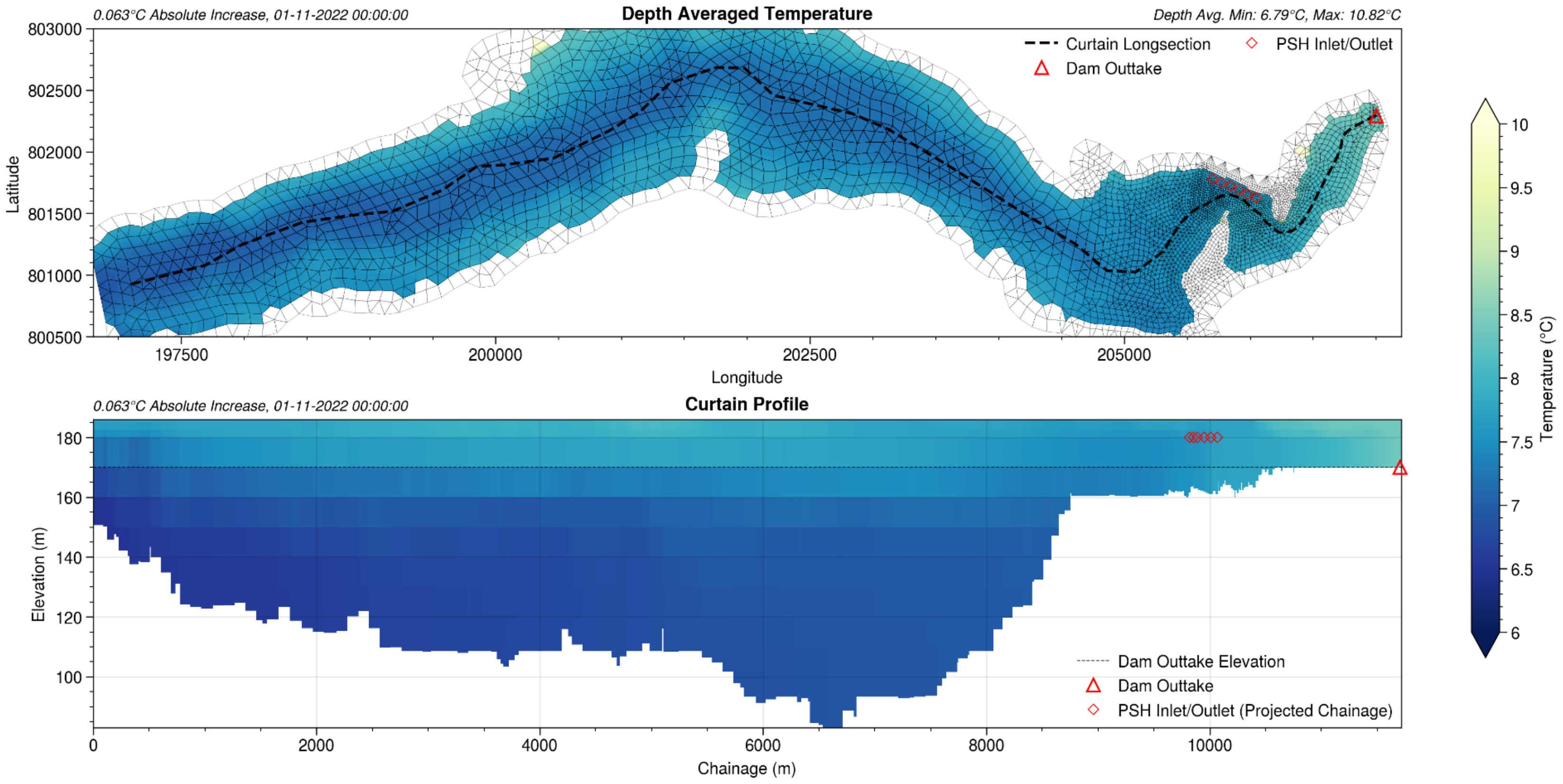


Figure 3-20: Curtain Plot of Temperature Difference Along Longitudinal Trace (PSH 0.063°C Increase at time 01/11/2022 00:00:00)

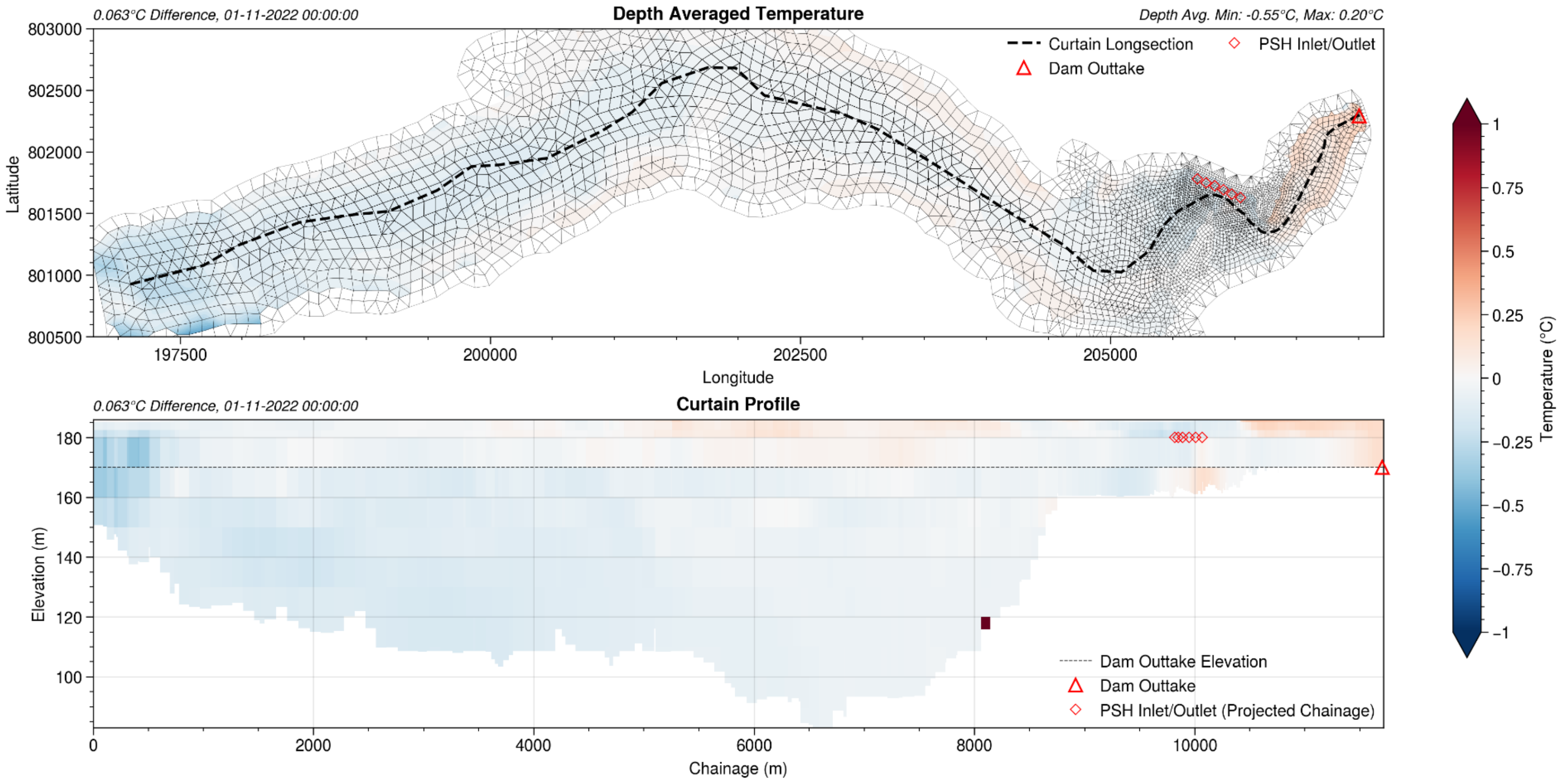


Figure 3-21: Curtain Plot of Temperature Profile Along Longitudinal Trace (PSH 0.063°C Increase at time 30/11/2022 00:00:00)

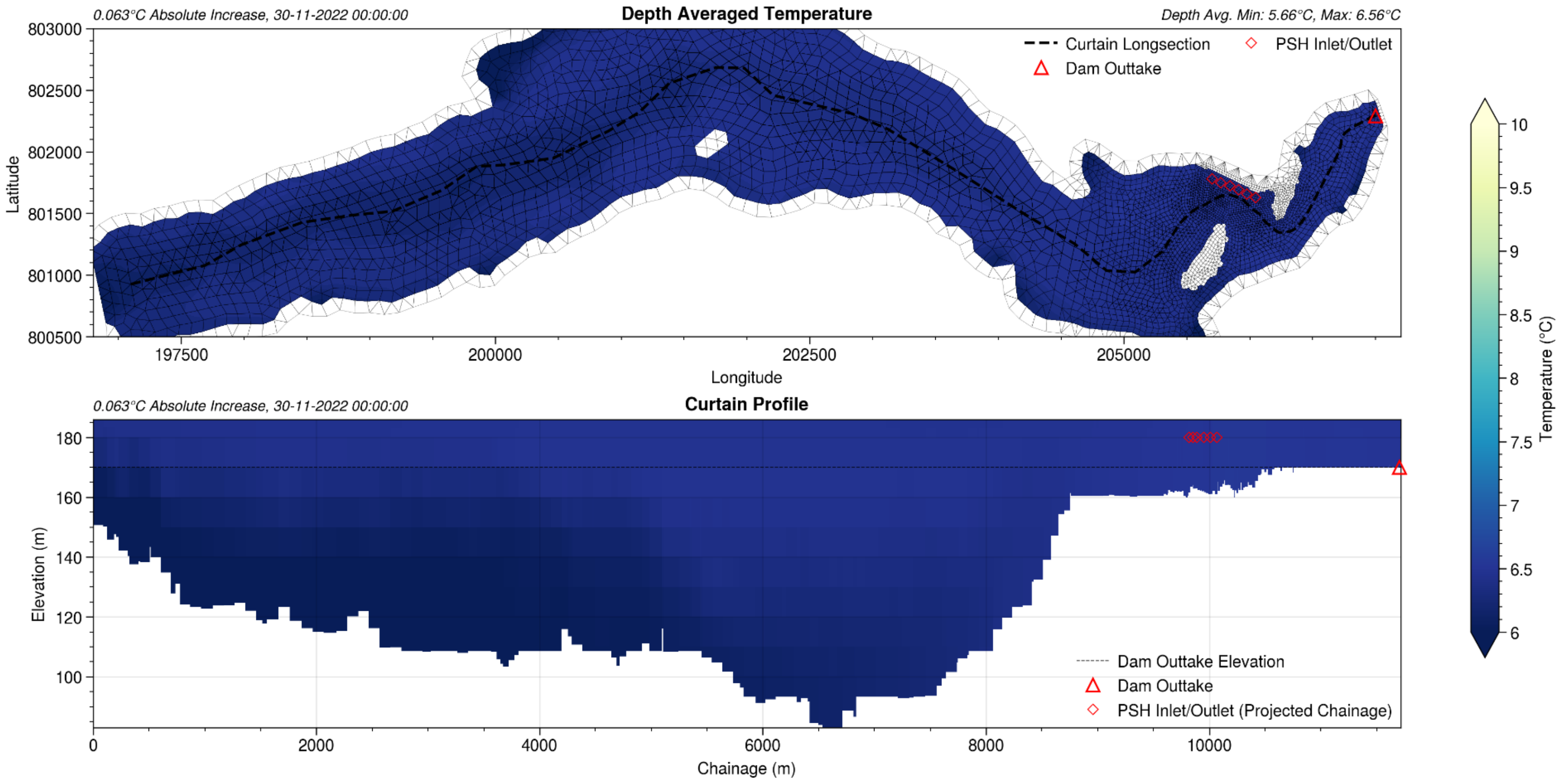


Figure 3-22: Curtain Plot of Temperature Difference Along Longitudinal Trace (PSH 0.063°C Increase at time 30/11/2022 00:00:00)

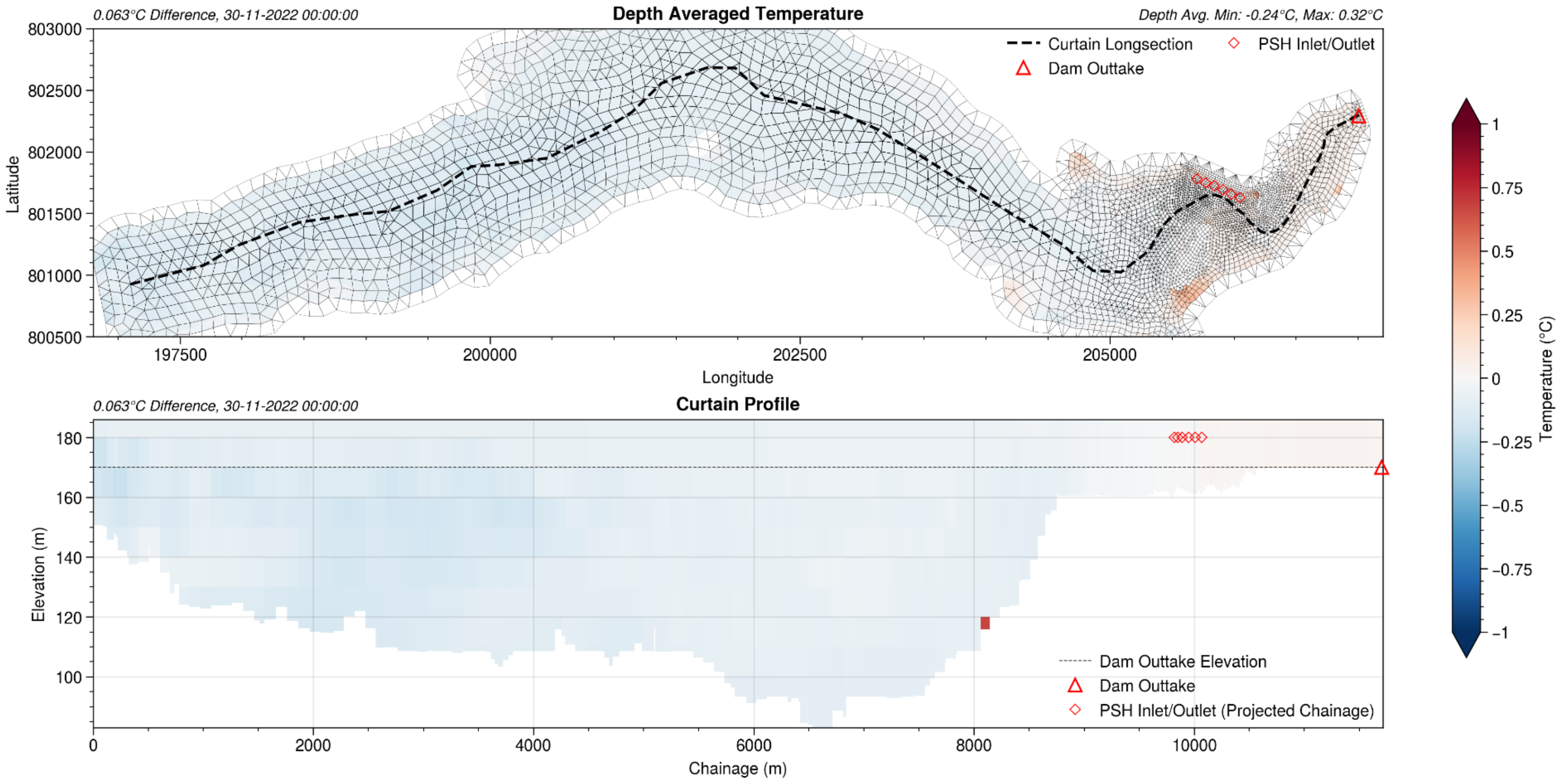


Figure 3-23: Curtain Plot of Temperature Profile Along Longitudinal Trace (PSH 0.063°C Increase at time 01/01/2023 00:00:00)

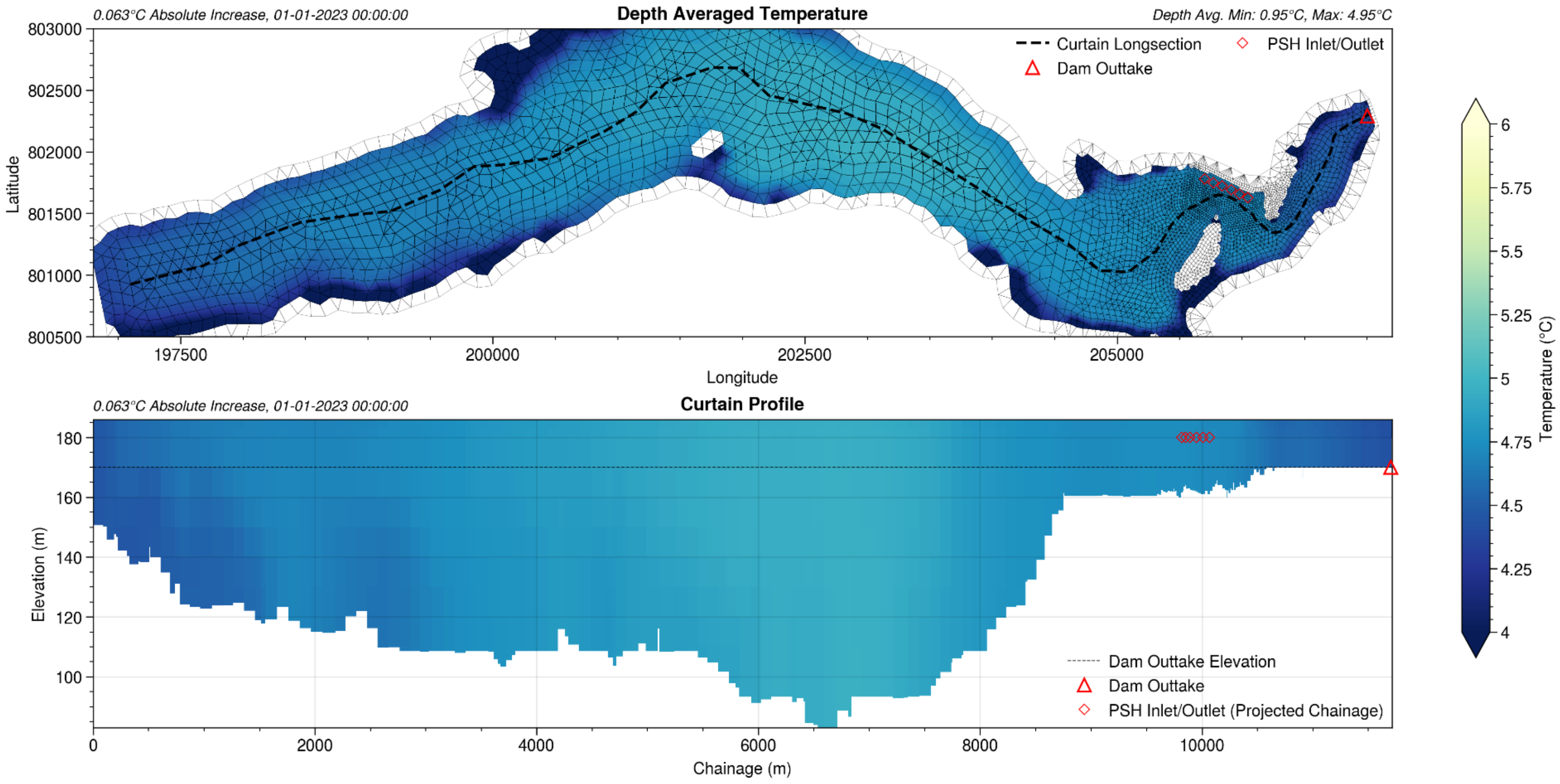


Figure 3-24: Curtain Plot of Temperature Difference Along Longitudinal Trace (PSH 0.063°C Increase at time 01/01/2023 00:00:00)

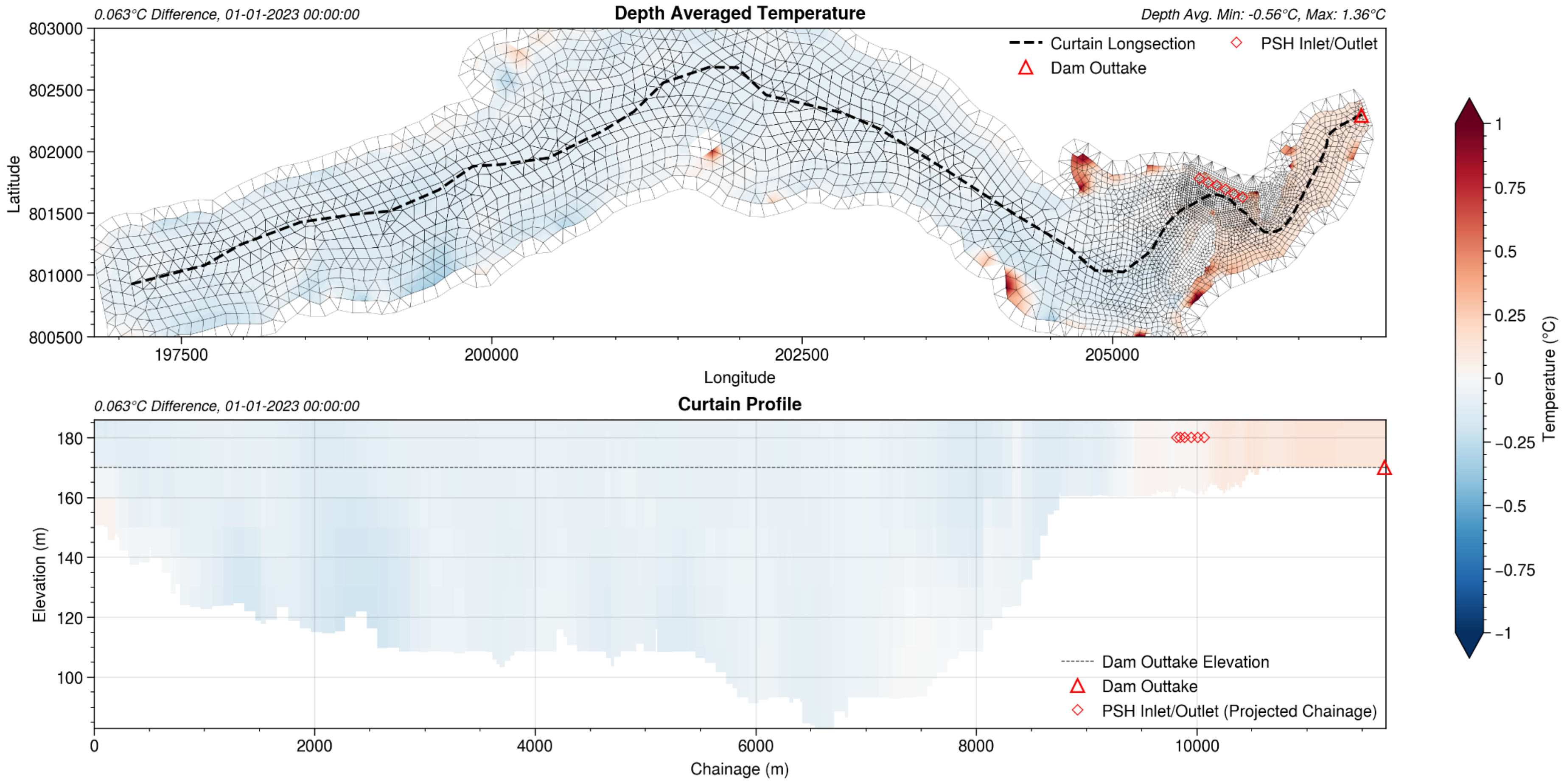


Figure 3-25: Vertical Temperature Profile at Dam Outtake (PSH 0.063°C Increase)

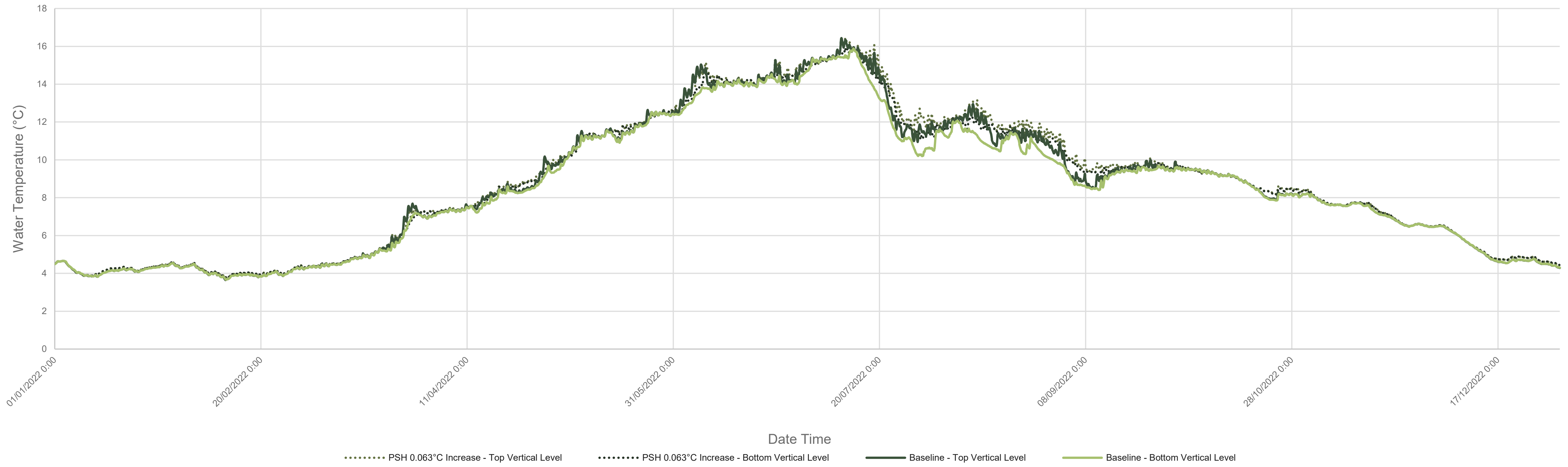


Figure 3-26: Vertical Temperature Profile at Dam Outtake (PSH 1% Increase)

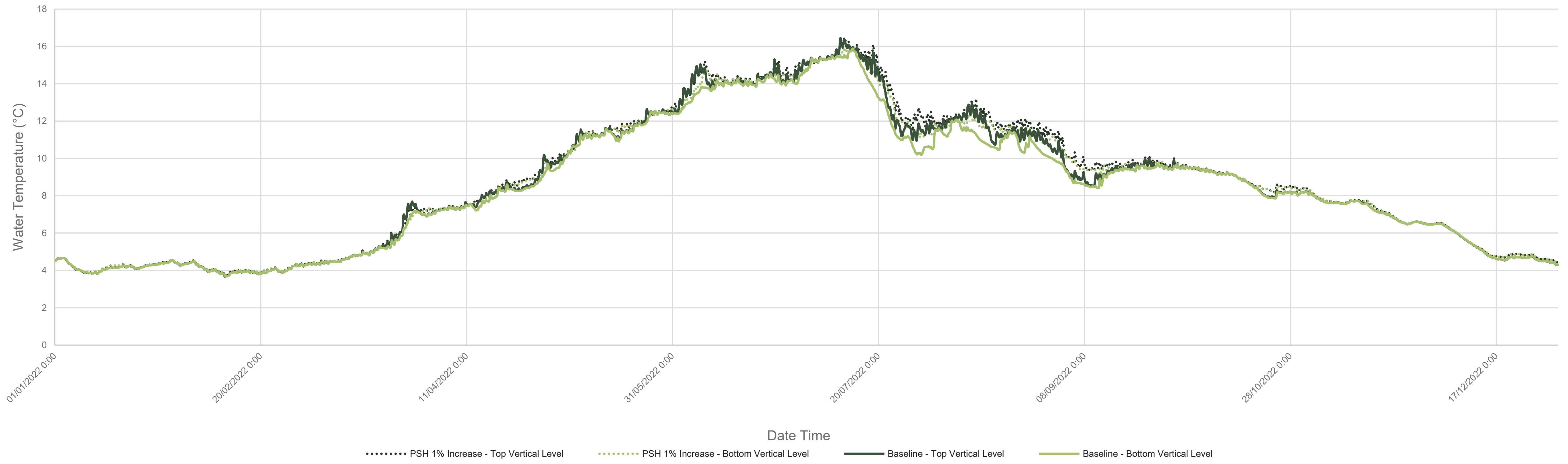
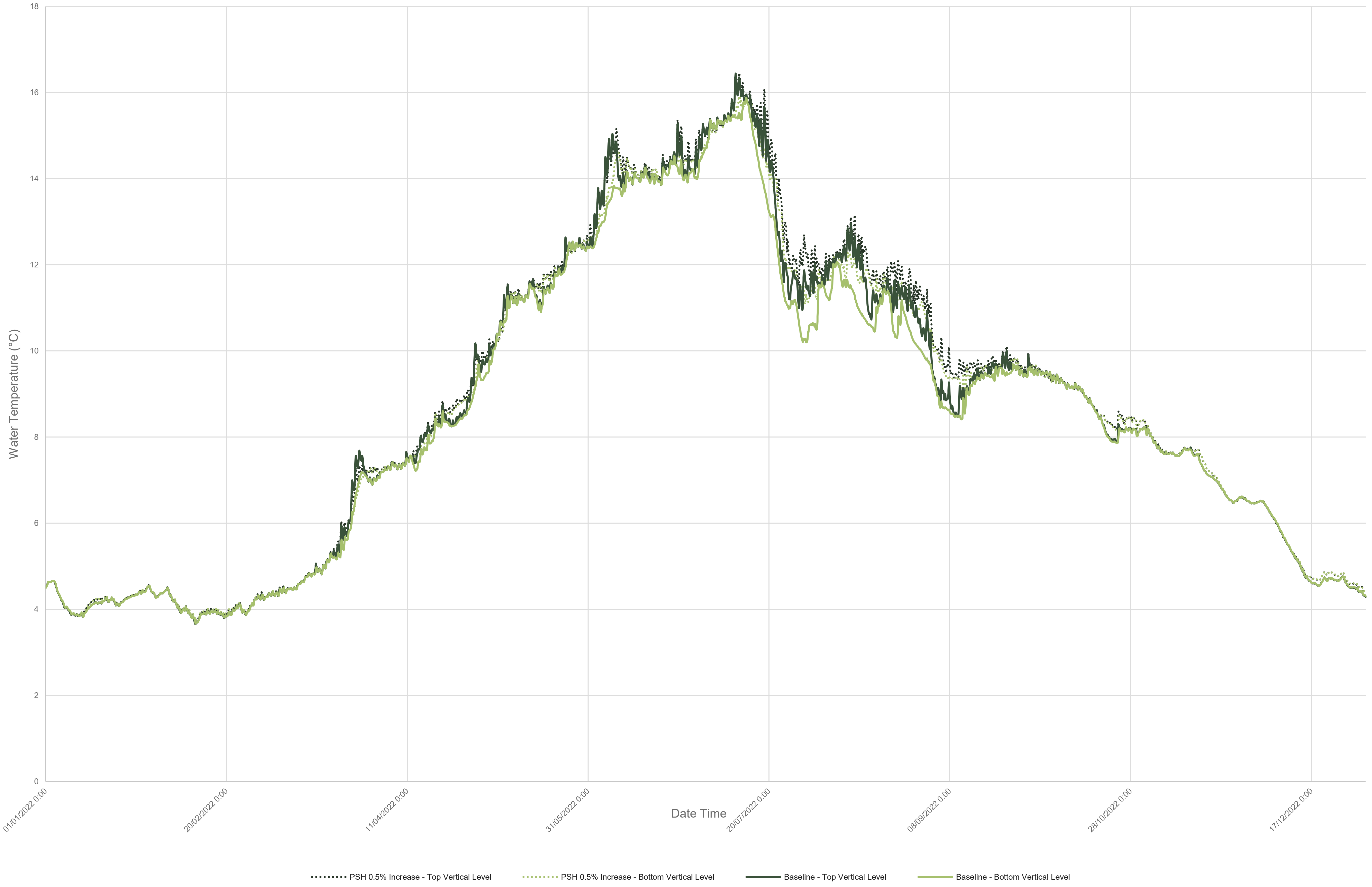


Figure 3-27: Vertical Temperature Profile at Dam Outtake (PSH 0.5% Increase)



3.2.3 Summary of 2022 PSH Results

3.2.3.1 Thermal Structure and Stratification

While the PSH may cause minor warming within Loch Quoich, the thermocline is still intact within the system during the warmer months. Looking at the 0.063°C increase scenario, from the curtain plot analysis above, at the 01/07/2022 timestep on the model it is evident that the thermocline has been shifted approximately 10-20m down. At the deepest part Loch Quoich (approximately 6500m chainage), results indicate a warming of 5.6°C in the base scenario to 6.7°C in the PSH scenario (+1.1°C). This temperature increase is visible in the difference plot provided for this timestep within Figure 3-18. Further depths within the loch at this timestep are seen to increase up to 2°C within the bottom half of the loch. This is attributed to the vertical mixing after a combined PSH inflow volume of 2,296,037,674 m³ during the previous six months up to July.

It is of note that the model predicts temperatures within Loch Quoich to return to approximately 4.5-5°C in the final timestep of the model suggesting that PSH operations have minor temperature impacts overall to the system.

3.2.3.2 Surface and Bottom Temperature Comparison at Dam Outtake

Table 3-3 and Table 3-4 present the modelled surface and bottom temperatures at the dam outtake for the final timestep of the simulation (01/01/2023 00:00:00), comparing baseline and PSH-influenced conditions.

Table 3-3: Baseline vs PSH Surface Temperatures (°C) at Outtake for Final Timestep

Scenario	Baseline Temperature	PSH Temperature	Difference
1% Increase	4.29	4.41	0.12
0.5% Increase	4.29	4.38	0.09
0.063°C Increase	4.29	4.42	0.13

Table 3-4: Baseline vs PSH Bottom Temperatures (°C) at Outtake for Final Timestep

Scenario	Baseline Temperature (°C)	PSH Temperature (°C)	Difference (°C)
1% Increase	4.30	4.42	0.12
0.5% Increase	4.30	4.40	0.09
0.063°C Increase	4.30	4.43	0.13

3.2.3.3 Temporal Temperature Differences at Outtake

To further assess the impact of PSH operations, the peak and average differences in temperature at the dam outtake were calculated for both surface and bottom layers over the simulation period. The PSH results were compared to the baseline results for the same timestep to understand the temperature difference at each timestep and statistics have been summarised in Table 3-5 and Table 3-6.

Table 3-5: PSH Top Temperatures at Outtake Difference

Scenario	Peak PSH Temperature Difference (°C)	Average PSH Temperature Difference (°C)
1% Increase	0.04	0.17
0.5% Increase	0.01	0.14
0.063°C Increase	0.00	0.16

Table 3-6: PSH Bottom Temperatures at Outtake Difference

Scenario	Peak PSH Temperature Difference (°C)	Average PSH Temperature Difference (°C)
1% Increase	0.04	0.21
0.5% Increase	0.03	0.19
0.063°C Increase	0.03	0.20

These results indicate that the thermal signal from PSH operations is both persistent and vertically distributed, with bottom layers showing slightly higher peak and average differences than surface layers. This is likely due to the large volume of inflow entering at the surface but in close proximity to the dam wall, where the outtake is located. The proximity of the warm surface inflow to the outtake allows for thermal entrainment and vertical mixing, which can elevate bottom temperatures even though the discharge itself is introduced at the surface.

3.2.3.4 Month by Month Comparison at Dam Outtake

To assess the temporal variability of thermal impacts from the PSH scheme, monthly peak and average temperature increases were analysed at the dam outtake for both the top and bottom vertical layers. The results are presented in Table 3-7 through Table 3-10.

Table 3-7: PSH Impacts Top Vertical Temperature – Monthly Peak Increases

Month	Baseline Average Temperature	Peak PSH Temperature Difference (°C)		
		1%	0.5%	0.063°C
January	4.66	0.00	0.00	0.01
February	4.50	0.04	0.02	0.06
March	7.69	-0.33	-0.34	-0.33
April	10.18	-0.14	-0.17	-0.15
May	12.64	0.34	0.29	0.30
June	15.28	0.12	0.09	0.08
July	16.44	0.04	0.01	0.00
August	12.95	0.26	0.22	0.22
September	10.94	0.55	0.50	0.51
October	9.58	0.14	0.11	0.12
November	8.22	0.19	0.16	0.18
December	6.51	0.04	0.01	0.04

Table 3-8: PSH Impacts Bottom Vertical Temperature – Monthly Peak Increases

Month	Baseline Average Temperature	Peak PSH Temperature Difference (°C)		
		1%	0.5%	0.063°C
January	4.66	0.00	0.00	0.01
February	4.50	0.04	0.02	0.05
March	7.19	0.10	0.09	0.11
April	9.69	0.17	0.13	0.15
May	12.54	0.18	0.14	0.15
June	14.53	0.32	0.28	0.29
July	15.88	0.04	0.03	0.03
August	12.07	0.26	0.22	0.21
September	9.86	1.06	1.01	1.02
October	9.56	0.14	0.11	0.12
November	8.21	0.17	0.14	0.16
December	6.51	0.04	0.01	0.04

Table 3-9: PSH Impacts Top Vertical Temperature – Monthly Average Increases

Month	Baseline	Average PSH Temperature Difference (°C)		
		1%	0.5%	0.063°C
January	4.22	0.04	0.03	0.05
February	4.01	0.06	0.05	0.08
March	5.24	0.02	0.00	0.03
April	8.00	0.14	0.12	0.14
May	11.36	0.13	0.10	0.10
June	14.13	0.17	0.14	0.14
July	14.14	0.34	0.31	0.31
August	11.57	0.40	0.37	0.37
September	9.41	0.41	0.39	0.40
October	8.76	0.12	0.10	0.11
November	7.26	0.06	0.04	0.06
December	5.16	0.08	0.06	0.09

Table 3-10: PSH Impacts Bottom Vertical Temperature – Monthly Average Increases

Month	Baseline	Average PSH Temperature Difference (°C)		
		1%	0.5%	0.063°C
January	4.22	0.04	0.03	0.05
February	4.02	0.06	0.05	0.08
March	5.15	0.04	0.03	0.05

Month	Baseline	Average PSH Temperature Difference (°C)		
		1%	0.5%	0.063°C
April	7.87	0.19	0.17	0.19
May	11.27	0.16	0.12	0.13
June	13.84	0.25	0.22	0.22
July	13.60	0.50	0.48	0.48
August	10.98	0.59	0.56	0.57
September	9.23	0.44	0.42	0.43
October	8.75	0.12	0.10	0.11
November	7.25	0.06	0.04	0.06
December	5.17	0.08	0.06	0.09

The monthly average temperature increases at the dam outtake over the 12-month simulation period show a seasonal pattern, with lowest impacts during winter months (January-March and November-December) and peak increases during summer (July-September). The 0.063°C increase scenario consistently results in the average temperature increases, reaching up to 0.40°C at the surface and 0.57°C at the bottom in September and August respectively.

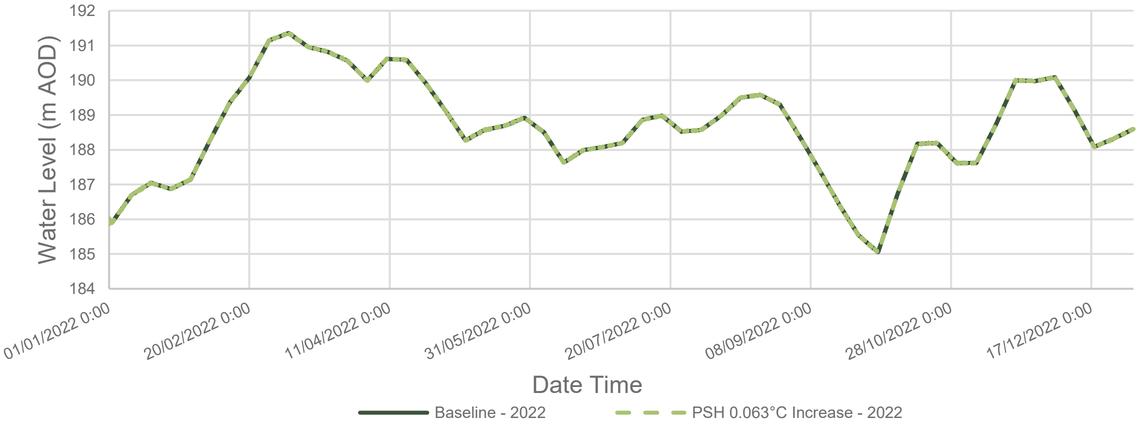
Bottom layers generally exhibit slightly higher average increases than surface layers, attributed to the large volume of surface-level PSH inflow entering close to the dam wall. This configuration promotes vertical mixing and entrainment, allowing warmer surface water to influence deeper layers.

These results indicate that the thermal effects associated with sustained PSH operations are relatively minor, however do highlight the value of considering both the scale and seasonal timing of releases to ensure minimal downstream influence.

3.2.4 Water Level Comparison

A comparison of water levels between the baseline and PSH 1-year scenario (2022) and baseline (2022) indicates that the influence of PSH flows on loch water levels is very minor. As shown in Figure 3-28, the water level profiles for both scenarios closely align throughout the simulation period, with only negligible deviations observed. This suggests that the operational flow volumes associated with PSH do not significantly alter the overall water level regime in the loch.

Figure 3-28: Water Level Comparison 2022



3.3 2020 to 2024 4-Year Simulation

3.3.1 Long-Form Simulation: Assessing Cumulative Thermal Impacts

To evaluate the cumulative thermal effects of sustained PSH operations, a long-form simulation was conducted covering the period from 01/01/2020 to 01/01/2024. While the original scope aimed to simulate five years, practical constraints (including data availability, model runtime, and output file size) necessitated a reduction to four years. This timeframe remains sufficient to capture seasonal and interannual variability and assess potential long-term thermal trends.

To manage computational demands, the model was configured to output daily temperature values rather than hourly. While this approach significantly reduced file size and improved runtime efficiency, it introduced limitations in capturing sub-daily temperature variability, particularly during PSH flow events. Specifically, the temperature applied to PSH inflows into the loch reflects a single daily value, rather than a dynamic hourly profile. This simplification may slightly suppress the simulated temperatures during PSH operations, as the inflow temperature does not always align with sub-daily air temperature fluctuations.

3.3.2 Application of PSH Operational Data Across the Long-Form Simulation

To simulate the cumulative thermal effects of PSH operations over a multi-year period, the 1-year PSH pump/generation schedule was extended and applied uniformly across the full 4-year simulation window (01/01/2020 to 01/01/2024). This approach was necessary due to the limited availability of long-term operational data and aimed to maintain consistency in flow patterns while enabling assessment of sustained thermal influence.

By repeating the same annual PSH operational cycle, the model assumes a consistent regime of pumping and generation events, allowing for the isolation of thermal impacts attributable to flow volumes and timing rather than interannual variability in operations. This method supports the study’s objective of identifying cumulative effects on loch temperature under a representative PSH scenario.

While this simplification does not capture potential year-to-year changes in PSH scheduling, it provides a controlled framework for evaluating how repeated operational patterns may influence long-term thermal dynamics. The results from this approach, when compared with baseline and 1-year simulations, indicate that the cumulative thermal impact remains minor, with temperature trends showing reasonable agreement across scenarios.

3.3.3 Temperature Assessment at Loch Quoich Outtake

To evaluate potential ecological impacts downstream and consistency with the previous scenario analysis, temperature results from the long-form simulation were specifically assessed at the Loch Quoich outtake, where flows enter the Gear Garry. This location was identified as a key point of interest due to known salmon and Arctic char spawning habitats within the Gear Garry.

Temporal top and bottom vertical temperature plots at the dam outtake have been provided for the 0.063°C scenario against the baseline results in Figure 3-29. A comparison of the 4-year PSH simulation with the baseline 4-year simulation shows marginally higher temperatures in the PSH scenario, consistent with expectations given the volume of flow applied with a daily temperature. However, when compared with the previous 1-year simulations, the overall thermal trends remain consistent, suggesting that the cumulative impact of PSH operations on loch temperature is minor to negligible over the four-year period. The differences seen between the 1-year to 4-year temperature results are related to the difference in modelling approach, i.e. the adoption of a daily temperature application.

Importantly, and summarised in Table 3-11 to Table 3-14, the seasonal timing of temperature peaks and troughs remains aligned across scenarios, suggesting that PSH operations do not significantly disrupt the natural thermal regime at the outlet. In the coldest month of February, maximum observed increases of up to +0.09°C (February 2020 peak temperature difference for top vertical layer, Table 3-13), suggesting that Loch Quoich temperatures at the outtake are not significantly impacted by cumulative effects.

These results support the conclusion that, under the proposed operational regime and modelling assumptions, sustained PSH activity does not significantly alter long-term thermal conditions in the loch.

Table 3-11: PSH Impacts Top Vertical Temperature at Dam Outtake – Yearly and Monthly Averages

Month	Top Average PSH Temperature Difference (°C)											
	2020			2021			2022			2023		
	Baseline	0.063°C	Difference	Baseline	0.063°C	Difference	Baseline	0.063°C	Difference	Baseline	0.063°C	Difference
January	4.33	4.37	**0.04**	3.95	4.10	**0.15**	4.83	4.91	**0.08**	4.37	4.49	**0.12**
February	4.00	4.06	**0.06**	3.29	3.31	**0.02**	4.39	4.45	**0.06**	4.72	4.75	**0.03**
March	4.24	4.29	**0.05**	4.47	4.47	**0.00**	5.24	5.28	**0.04**	4.84	4.89	**0.05**
April	6.60	6.67	**0.07**	6.42	6.47	**0.05**	7.80	7.89	**0.09**	6.78	7.06	**0.28**
May	9.26	9.44	**0.18**	8.49	8.85	**0.36**	11.51	11.58	**0.07**	9.56	9.77	**0.21**
June	9.84	10.10	**0.26**	11.43	11.70	**0.27**	14.73	14.80	**0.07**	11.90	12.26	**0.36**
July	11.52	11.64	**0.12**	13.38	13.68	**0.30**	15.74	15.89	**0.15**	11.70	12.07	**0.37**
August	10.62	11.11	**0.49**	11.92	12.64	**0.72**	13.60	13.90	**0.30**	10.77	11.19	**0.42**
September	9.62	9.87	**0.25**	10.17	10.56	**0.39**	11.08	11.46	**0.38**	10.47	10.83	**0.36**
October	8.05	8.17	**0.12**	8.72	8.70	**-0.02**	9.82	9.89	**0.07**	8.52	8.62	**0.10**
November	6.80	6.82	**0.02**	7.27	7.27	**0.00**	8.16	8.21	**0.05**	6.27	6.30	**0.03**
December	5.51	5.58	**0.07**	5.45	5.53	**0.08**	5.71	5.80	**0.09**	5.09	5.16	**0.07**

Table 3-12: PSH Impacts Bottom Vertical Temperature at Dam Outtake – Yearly and Monthly Averages

Month	Bottom Average PSH Temperature Difference (°C)											
	2020			2021			2022			2023		
	Baseline	0.063°C	Difference	Baseline	0.063°C	Difference	Baseline	0.063°C	Difference	Baseline	0.063°C	Difference
January	4.33	4.38	**0.05**	3.97	4.11	**0.14**	4.84	4.91	**0.07**	4.37	4.49	**0.12**
February	4.01	4.07	**0.06**	3.30	3.31	**0.01**	4.39	4.46	**0.07**	4.72	4.76	**0.04**
March	4.24	4.30	**0.06**	4.48	4.47	**-0.01**	5.17	5.22	**0.05**	4.84	4.89	**0.05**
April	6.26	6.45	**0.19**	6.22	6.35	**0.13**	7.69	7.83	**0.14**	6.64	6.95	**0.31**
May	8.62	9.08	**0.46**	8.08	8.62	**0.54**	11.44	11.53	**0.09**	9.09	9.47	**0.38**
June	8.97	9.54	**0.57**	10.64	11.14	**0.50**	14.46	14.61	**0.15**	10.57	11.44	**0.87**
July	10.95	11.33	**0.38**	11.77	12.86	**1.09**	15.44	15.69	**0.25**	10.79	11.51	**0.72**
August	9.98	10.67	**0.69**	11.50	12.40	**0.90**	13.19	13.63	**0.44**	10.12	10.76	**0.64**
September	9.50	9.79	**0.29**	10.16	10.55	**0.39**	10.95	11.36	**0.41**	10.25	10.66	**0.41**
October	8.04	8.16	**0.12**	8.73	8.71	**-0.02**	9.82	9.89	**0.07**	8.50	8.60	**0.10**
November	6.81	6.83	**0.02**	7.28	7.28	**0.00**	8.16	8.21	**0.05**	6.28	6.30	**0.02**
December	5.51	5.59	**0.08**	5.46	5.53	**0.07**	5.72	5.80	**0.08**	5.10	5.16	**0.06**

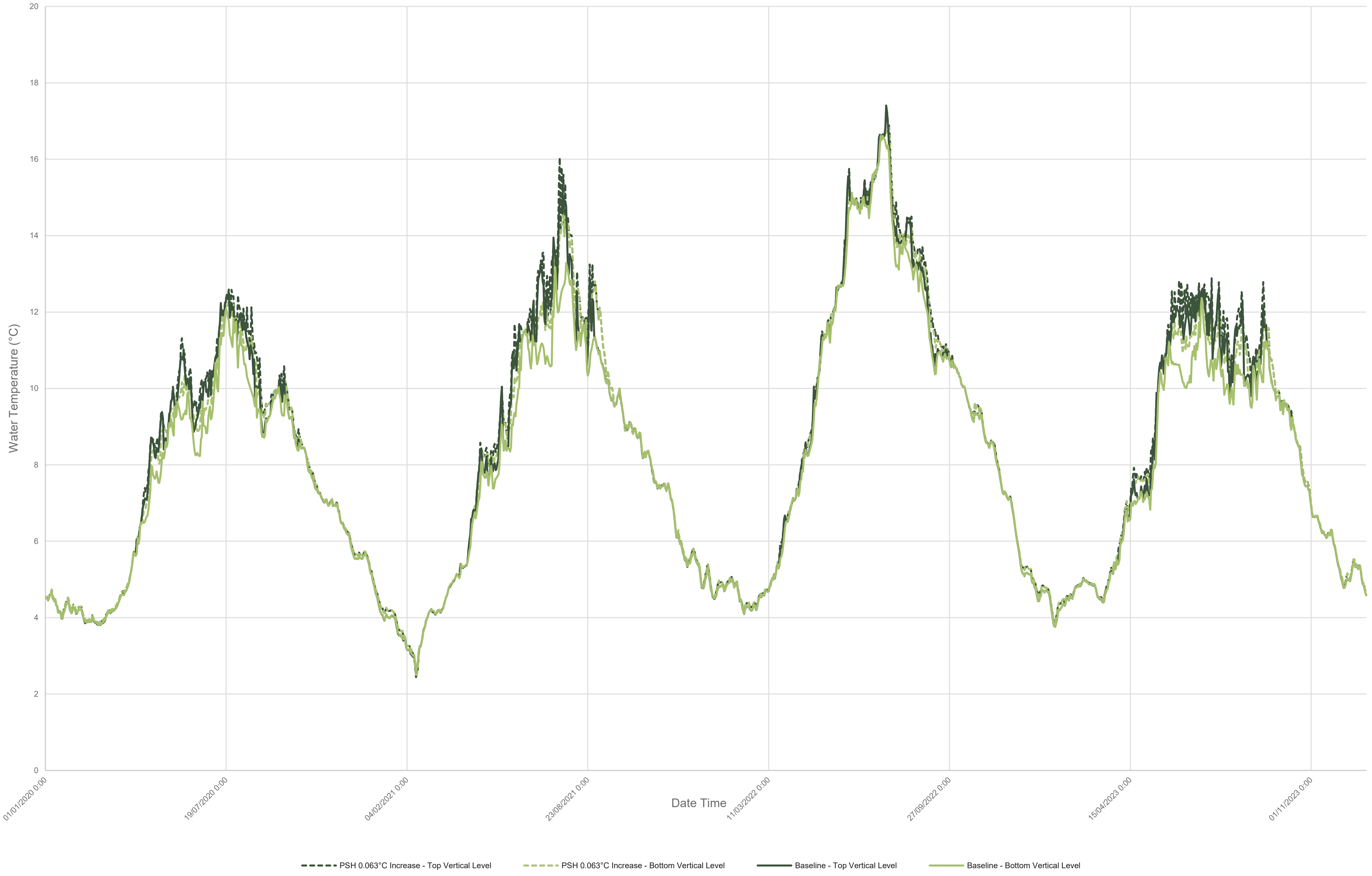
Table 3-13: PSH Impacts Top Vertical Temperature at Dam Outtake – Yearly and Monthly Peaks

Month	Top Peak PSH Temperature Difference (°C)											
	2020			2021			2022			2023		
	Baseline	0.063°C	Difference	Baseline	0.063°C	Difference	Baseline	0.063°C	Difference	Baseline	0.063°C	Difference
January	4.69	4.73	**0.04**	4.60	4.69	**0.09**	5.28	5.39	**0.11**	4.72	4.84	**0.12**
February	4.26	4.35	**0.09**	4.12	4.13	**0.01**	4.91	4.94	**0.03**	5.02	5.03	**0.01**
March	4.74	4.81	**0.07**	5.14	5.14	**0.00**	6.67	6.59	**-0.08**	5.52	5.60	**0.08**
April	8.72	8.67	**-0.05**	8.40	8.58	**0.18**	10.05	9.89	**-0.16**	7.62	7.92	**0.30**
May	10.83	11.32	**0.49**	10.42	10.77	**0.35**	12.70	12.80	**0.10**	11.90	12.55	**0.65**
June	11.02	11.04	**0.02**	12.98	13.08	**0.10**	15.56	15.76	**0.20**	12.58	12.83	**0.25**
July	12.51	12.59	**0.08**	14.98	16.04	**1.06**	17.41	17.34	**-0.07**	12.58	12.88	**0.30**
August	11.94	12.44	**0.50**	13.52	14.49	**0.97**	14.46	14.51	**0.05**	12.25	12.53	**0.28**
September	10.28	10.58	**0.30**	11.22	12.61	**1.39**	12.64	13.13	**0.49**	12.12	12.78	**0.66**
October	9.00	9.22	**0.22**	9.33	9.35	**0.02**	10.58	10.66	**0.08**	9.59	9.69	**0.10**
November	7.16	7.17	**0.01**	8.02	8.00	**-0.02**	9.32	9.46	**0.14**	6.91	6.96	**0.05**
December	6.16	6.23	**0.07**	6.21	6.27	**0.06**	7.12	7.17	**0.05**	5.45	5.53	**0.08**

Table 3-14: PSH Impacts Bottom Vertical Temperature at Dam Outtake – Yearly and Monthly Peaks

Month	Bottom Peak PSH Temperature Difference (°C)											
	2020			2021			2022			2023		
	Baseline	0.063°C	Difference	Baseline	0.063°C	Difference	Baseline	0.063°C	Difference	Baseline	0.063°C	Difference
January	4.69	4.73	**0.04**	4.61	4.70	**0.09**	5.28	5.39	**0.11**	4.72	4.84	**0.12**
February	4.26	4.34	**0.08**	4.12	4.13	**0.01**	4.92	4.96	**0.04**	5.02	5.03	**0.01**
March	4.74	4.81	**0.07**	5.14	5.13	**-0.01**	6.52	6.60	**0.08**	5.52	5.61	**0.09**
April	7.96	8.38	**0.42**	8.08	8.33	**0.25**	9.21	9.31	**0.10**	7.30	7.70	**0.40**
May	9.65	10.16	**0.51**	9.05	9.94	**0.89**	12.70	12.80	**0.10**	11.21	11.64	**0.43**
June	9.91	10.36	**0.45**	11.50	11.86	**0.36**	15.03	15.22	**0.19**	11.74	12.06	**0.32**
July	12.08	12.33	**0.25**	13.28	14.59	**1.31**	16.61	16.83	**0.22**	12.37	12.56	**0.19**
August	11.52	11.86	**0.34**	13.07	14.35	**1.28**	13.94	14.21	**0.27**	10.65	11.61	**0.96**
September	10.04	10.23	**0.19**	11.20	12.60	**1.40**	12.15	12.98	**0.83**	11.24	11.88	**0.64**
October	8.96	9.12	**0.16**	9.33	9.35	**0.02**	10.58	10.67	**0.09**	9.59	9.69	**0.10**
November	7.17	7.18	**0.01**	8.03	8.01	**-0.02**	9.31	9.44	**0.13**	6.92	6.98	**0.06**
December	6.17	6.24	**0.07**	6.22	6.29	**0.07**	7.13	7.18	**0.05**	5.45	5.52	**0.07**

Figure 3-29: Vertical Temperature Profile at Dam Outtake (PSH 0.063°C Absolute Increase)



4.0 Discussion

The modelling results confirm that Loch Quoich is a thermally stratified system during summer months, with a stable thermocline that isolates cooler bottom waters from warmer surface layers. This stratification is ecologically important, supporting cold-water habitats and influencing downstream thermal regimes.

The introduction of PSH operations, particularly with surface-level inflows located near the dam wall, has the potential to alter this natural stratification. Although the discharge enters at the surface, the volume and proximity of the inflow to the dam outtake appear to influence the thermal structure at depth. This is likely due to localised mixing effects from the PSH inflow, which allow warmer surface water to affect the temperature of water extracted at the dam base. While the PSH may cause minor warming within Loch Quoich, the thermocline is still intact within the system during warmer periods.

The modelling has shown that even modest increases in discharge temperature (e.g., 0.063°C) can result in detectable warming at the dam outtake. Higher temperature scenarios (1% increase) lead to more pronounced thermal impacts, including elevated bottom temperatures and increased vertical mixing.

The model’s performance was validated against observed data, showing strong alignment in bottom layers and good trend matching at the surface. Some discrepancies in short-term variability are attributed to the model’s vertical resolution, which can smooth diurnal fluctuations.

The 4-year simulation provides a robust framework for assessing the cumulative thermal effects of sustained PSH operations at Loch Quoich. By applying a repeated annual pump/generation schedule and simplifying outputs to daily temperature values, the model captures long-term trends while managing computational constraints. Analysis at the loch outlet, where flows enter the Gear Garry, reveals only a marginal increase in temperature under the PSH scenario, suggesting that operational flows do not significantly disrupt the thermal regime.

5.0 Conclusions and Recommendations

The modelling study concluded that Loch Quoich exhibits strong seasonal thermal stratification under natural conditions, with a well-defined thermocline forming during warmer months. The introduction of the Fearna Pump Storage Hydro (PSH) scheme, particularly with surface-level inflows located close to the dam wall, has the potential to alter this thermal structure.

Simulations have shown that even modest increases in discharge temperature, such as the scientifically derived 0.063°C per cycle, can result in detectable warming at the dam outtake.

The model demonstrated strong agreement with observed data, especially in bottom layers, validating its reliability for impact assessment. Based on these findings, this report recommends long-term monitoring to manage and understand the potential thermal impacts of the PSH scheme.

Results from the long-form simulation indicate that sustained PSH operations, under the proposed regime, have a minor to negligible cumulative impact on loch outlet temperatures. The observed increase of up to +0.09°C in the winter month of February, is consistent with expectations given the modelling approach. Seasonal temperature patterns remain intact, supporting the conclusion that PSH activity has minor to negligible cumulative impacts.

The following recommendations have been made to potentially increase the understanding of both the PSH Scheme and Loch Quoich itself:

- Monitoring Programme: Implement long-term temperature monitoring upstream and downstream of the dam to validate model predictions and track real-world impacts.
- Model Refinement: Consider higher vertical resolution in future modelling to better capture short-term surface variability.

6.0 Closure

This report has been prepared by SLR Consulting Ltd. with reasonable skill, care, and diligence, in accordance with the terms of our appointment by Fearna Pump Storage Hydro Limited. The findings and recommendations presented herein are based on the best available data and modelling tools at the time of writing. Any use of this report by third parties is subject to the terms and limitations outlined in the Basis of Report.

We trust this report provides a robust and transparent assessment of the potential thermal impacts of the Fearna PSH scheme. Should further clarification or support be required, we remain available to assist.

Regards,

SLR Consulting Limited

[redacted]

Associate Hydraulic Modeller
Hydrology & Hydrogeology

[redacted]

Principal Flood Risk Consultant
Hydrology & Hydrogeology

Appendix A Gilkes - Hourly PHS Actions and State of Charge Over - 2034

Fearna PSH - TUFLOW FV 3D Modelling Report

Assessment of Temperature Variance in Loch Quoich

Fearna PSH Limited

SLR Project No.: 405.065932.00001

15 September 2025

Appendix B Mott MacDonald Fearna PSH Temperature Investigation Extract

Fearna PSH - TUFLOW FV 3D Modelling Report

Assessment of Temperature Variance in Loch Quoich

Fearna PSH Limited

SLR Project No.: 405.065932.00001

15 September 2025

Appendix C Proposed PSH Development Plans

Fearna PSH - TUFLOW FV 3D Modelling Report

Assessment of Temperature Variance in Loch Quoich

Fearna PSH Limited

SLR Project No.: 405.065932.00001

15 September 2025

Appendix D Fearna Pumped Storage Hydro Scheme – EIA Report[3]

Fearna PSH - TUFLOW FV 3D Modelling Report

Assessment of Temperature Variance in Loch Quoich

Fearna PSH Limited

SLR Project No.: 405.065932.00001

15 September 2025

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[3] https://fearnastorage.co.uk/documents/

Appendix E PSH Sensitivity (1% and 0.5% Temperature Increase) Curtain Plots

Fearna PSH - TUFLOW FV 3D Modelling Report

Assessment of Temperature Variance in Loch Quoich

Fearna PSH Limited

SLR Project No.: 405.065932.00001

15 September 2025

Appendix F PSH 0.063°C Temperature Increase Curtain Plot Animations

Fearna PSH - TUFLOW FV 3D Modelling Report

Assessment of Temperature Variance in Loch Quoich

Fearna PSH Limited

SLR Project No.: 405.065932.00001

15 September 2025

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