Cruachan Power Station Units 3 & 4 Upgrade Project

Hydrological Assessment

On behalf of Drax

Project Ref: 331201279 | Rev: AA | Date: January 2023

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For and on behalf of Stantec UK Limited				

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1 Introduction

1.1 Objectives

The objective of this assessment and document is to establish the impact that the Cruachan 1 Unit 3 and 4 replacement will have on water resources. Specifically, the impact that the proposals will have on water level variability within Cruachan Reservoir and Loch Awe have been examined. This has been achieved through the analysis of historical water level time series data for Cruachan Reservoir and Loch Awe. The causal mechanisms driving historical water level variability within each water body are explained and the interdependency between the water level time series quantified. The likely impact of the proposed development has, therefore, been assessed within the context of these causal mechanisms and water level interdependency.

1.2 Environmental Impact Assessment – Screening Opinion

In June 2022 a formal request for an EIA Screening Opinion was issued to the Energy Consents Unit to ascertain whether the proposed development would require an Environmental Impact Assessment. In October 2022 a formal response was received from the Energy Consents Unit (ECU) confirming 'no EIA' was required. Although no EIA was required the ECU did request that a number of studies were undertaken, reported, and submitted to support any subsequent section 36 application. Two of these are as follows and this assessment document constitutes a response on these two topic areas.

- Hydrological Assessment; and
- Assessment of impact on private water supplies from construction through to operation.

1.3 Background

The existing Cruachan power station (Cruachan 1), owned and managed by Drax, is a pumped storage hydroelectric plant. It draws on water from Loch Awe to store potential energy in Cruachan Reservoir, which it subsequently releases in periods of high energy demand from the National Grid; the difference in water level between the two water bodies is approximately 350m.

The locations of Loch Awe and the Cruachan Reservoir are shown in Figure 1. Loch Awe has a topographical catchment area of approximately 813 km^2, which is fairly steep-sided and encompasses narrow valleys, steep grass-covered slopes and two natural lochs: Loch Tulla and Loch Avich. Cruachan Reservoir is impounded by the Cruachan Dam and has a much smaller topographical catchment area of approximately 5.87 km^2. Its catchment is also steep-sided and grass-covered. The effective catchment area of the Cruachan Reservoir is, however, increased due to the presence of aqueducts, which transfer water via gravity from rivers in adjacent catchments (this is discussed further below).

Cruachan 1 had an upgrade during 2002 – 2004, with turbine "Units" 1 and 2 upgraded to provide greater overall capacity.

1.4 Proposed Development

The development proposal is to replace the original Cruachan 1 Units 3 and 4 with new Units of a capacity similar to those already upgraded Units 1 and 2. The increase in capacity as a result of the replacements will increase each new Unit from the existing 100 MW to 120 MW (480 MW for the scheme in total).

The scheme will continue to use Loch Awe for abstraction and the Cruachan Reservoir for storage and generation, as such the principle of its operating regime will be identical to the existing regime.

The instantaneous flow capacity of upgraded Units 3 and 4 will be slightly greater than the original units, allowing water to be transferred from Loch Awe to the Cruachan Reservoir at a marginally greater rate than has occurred to date. The proposals do not, however, involve an increase in the overall volume of water abstracted from Loch Awe to Cruachan Reservoir, and no alteration to Drax's existing abstraction license is sought. As such, the proposed upgrade to Cruachan 1 is not expected to impact water resource availability within Loch Awe.

The proposals are likely to create a minor increase in the maximum storage capacity currently available within the Cruachan Reservoir, where the lower operating level of the Reservoir is likely to be dropped by around 2m, (from the existing operating range of 377m – 400mAOD to a proposed 375m – 400mAOD) allowing an increase in the maximum operating range of the Reservoir.

The reduction in minimum operating level in the Cruachan Reservoir is, however, only required to allow the Applicant to draw down water levels to a lower elevation to facilitate periodic maintenance and would not represent a change to the routine water level variability in the Reservoir. The normal operational water level range within the reservoir will not, therefore, significantly change with the scheme in place (with lower water levels likely to only occur during periods of infrequent routine maintenance).

2 Impact on Water Levels within Cruachan Reservoir

2.1 Overview

Cruachan 1 functions as a load-leveler to the National Grid, using excess energy during periods of low demand to pump water up from Loch Awe to the Cruachan Reservoir, then releasing it through the turbines to generate energy during periods of high demand.

With Cruachan 1 Unit 3 and 4 replacements in place, overall power generation will increase from 440 to 480MWe. As power generation is directly related to the rate and volume of water discharge, this means that the combined existing and proposed Unit upgrade will be able to drain and fill Cruachan Reservoir more quickly than at present.

Cruachan Reservoir currently has an operational water level range of between 377m AOD (Black Start level) and 400m AOD (maximum operational level); this is a maximum water level range of 23m. Water level variability within the reservoir is changeable and governed by demand and antecedent conditions, although typically water levels pass through much of this range and back once or more per week and, at times, more frequently. The maximum operational water level boundary will be maintained with thCruae proposed development in place, however the minimum level is proposed to drop to a level of 375m AOD.

The reduction in minimum operating level in the Cruachan Reservoir is, however, only required to allow the Applicant to draw down water levels to a lower elevation to facilitate periodic maintenance and would not represent a change to the routine water level variability in the reservoir. The normal operational water level range within the reservoir will not, therefore, significantly change with the proposed development in place (with lower water levels likely to only occur during periods of infrequent routine maintenance).

The inflows to the Reservoir include, in order of magnitude:

- Water pumped up from Loch Awe;
- Water imported by gravity drainage from adjacent catchments via the Main, Brander and Awe Village aqueducts; and
- Natural rainfall-runoff from its modest topographical catchment.

The outflows from the Reservoir include the discharge for power generation back to Loch Awe – losses via evaporation and leakage are not considered to be significant by comparison.

2.2 Timeseries Analysis

Drax has provided a time series of water levels within the Cruachan Reservoir from 2015 to May 2021. The time step for the water level data is 6 hours; sufficient to discern sub-daily variation. Figure 2 shows a collection of timeseries plots of water levels within the Cruachan Reservoir. The time series demonstrates how water levels within the reservoir pass through much of the operational range on a regular, near-cyclical, basis.

The amplitude and frequency of variation in water level are both significant. The rate and extent of water level rise and decline within the Reservoir far exceeds that which might be expected to occur within a ‘natural’ system. The time series displays frequent examples of near-weekly cyclicity in water level variation: water levels in the Reservoir can rise at the start of a week as water is abstracted from Loch Awe and the Reservoir fills; water levels fall towards the end of the week as water is released back into Loch Awe to generate energy.

2.3 Water Balance Analysis

Drax has also provided data on daily abstractions from Loch Awe to the Cruachan Reservoir; daily generation discharges from the reservoir back to Loch Awe; daily inflows from the three gravity aqueducts; and daily rainfall. Figure 3 shows the results of a monthly water balance analysis undertaken using these data[1].

The current operation of Cruachan 1 (i.e., pumping from Loch Awe and discharges back for power generation) comprises the near-totality of the monthly water balance (Figure 3). The pumped inflows and discharges for power generation are the dominant features of the water balance; they are many times greater in magnitude than the other components. Over a monthly timescale, net storage change mostly cancels out. The aqueducts provide a smaller but significant inflow although natural runoff from the topographical catchment is less significant in comparison.

2.4 Statistical Analysis

The dominance of the current operation of Cruachan 1 on the water level regime at Cruachan Reservoir is further demonstrated by statistical analysis. Plotting water level change within a day (midnight to midnight) against daily flow components reveals correlations between water level and flow components. The correlation can be quantified by the R^2 metric (for which 0 represents no correlation and 1 represents a perfect linear relationship). This analysis is shown in Figure 4. Of all the contributing factors analysed, the power station operational balance (pumping minus generation) shows the greatest correlation with water level variation, giving an R^2 of 0.81. Inflows from the gravity aqueducts and natural catchment runoff both appear to have little influence on the rate of water level change in the reservoir (with R^2 values at ca. 0.04 and 0.01 respectively).

2.5 Conclusion

The rate and extent of water level rise and decline within the reservoir far exceeds that which might be expected to occur within a ‘natural’ system. The amplitude and frequency of variation in water level are both significant. Water levels within the reservoir pass through much of the proposed operational range (i.e., between 375m and 400m AOD) on a regular, near-cyclical basis.

The water balance analysis concludes that the water level regime in Cruachan Reservoir is almost entirely artificially controlled. The statistical analysis shows that water level rise and fall in Cruachan Reservoir is closely controlled by the operation of Cruachan 1 (i.e., pumping from Loch Awe and discharges back for power generation), and not significantly influenced by gravity inflows from the aqueducts or by natural rainfall-runoff.

The maximum operational water level range within the reservoir will increase by a proposed 2m increase with the proposed development in place. This will be by reducing the minimum operating level of the Reservoir by 2m from the current minimum 377mAOD to 375mAOD. The reduction in minimum operating level in the Cruachan Reservoir is, however, only required to allow the Applicant to draw down water levels to a lower elevation to facilitate periodic maintenance and would not represent a change to the routine water level variability in the reservoir. The normal operational water level range within the Reservoir will not, therefore, significantly change with the proposed development in place (with lower water levels likely to only occur during periods of infrequent routine maintenance).

[1] For this analysis, it was assumed that 100% of all rainfall falling within the modest topographical catchment draining to the Cruachan Reservoir is converted directly to runoff. This assumption is likely to over-estimate the contribution of natural runoff to the Cruachan Reservoir water balance.

The instantaneous flow capacity of replaced Units 3 and 4 will, however, be slightly greater than the original units, allowing water to be transferred from Loch Awe to the Cruachan Reservoir at a marginally greater rate than has occurred to date.

The principal impact of the proposed develoment will, therefore, be that the rate at which water levels within the Reservoir could rise and fall in the future would be more rapid than at present. The significant water level dynamics are shown in Figure 2 below. The maximum and minimum operational water levels that would be achieved with the proposed development in place would, however, be similar to the reservoir's "normal" operational levels as illustrated by the black lines shown in Figure 2, as has been the case to date. Therefore, the nature of the water level regime in Cruachan Reservoir will not fundamentally change beyond the proposed 2m change, since artificial factors are already by far dominant over naturally driven variation.

3 Impact on water levels on Loch Awe

Loch Awe is impounded by the Loch Awe Barrage. The barrage is operated by Scottish and Southern Energy (SSE). The Barrage controls water levels within Loch Awe to provide working storage for hydropower generation at SSE's Inverawe Power Station. SSE operates the barrage to maintain target water level ranges for power generation of between 36.27 to 37.06m AOD (from April to November), and 35.96 to 36.57m AOD (from December to March).

The barrage operates in 'flood-release' mode when water levels within Loch Awe exceed 37.06 and 36.57m AOD during these two respective periods. During periods of low rainfall or drought conditions, SSE either limits or halts power generation at its Inverawe Power Station, and modulates the outflow rate from the barrage, until water levels within the Loch recover to within the aforementioned ranges. The barrage appears to have a minimum invert level of 35.35m AOD. Drax and SSE have an agreement (Distress Agreement) relating to the operational arrangements of Loch Awe.

Relative to the Cruachan Reservoir, Loch Awe has a large surface area, topographical catchment, and storage volume. Drax has provided a time series of water levels recorded within Loch Awe. The water level gauge from which this time series is sourced is located close to the existing inlet/outlet of Cruachan 1. The following timeseries and statistical analyses examine the interdependencies between the current operation of Cruachan 1 and water levels within Loch Awe, and between natural rainfall-runoff within the Loch Awe catchment and its attendant water level variability.

3.1 Timeseries Analysis

The responses of water levels within Loch Awe to rainfall and the operation of Cruachan 1 can be illustrated by investigating sections of the timeseries data. Figure 5**Error! Reference source not found.** illustrates that periods of rainfall in early September and late October 2020 produced a clear high water level response in Loch Awe. However, during a period of no rainfall between 12th and 18th October, Loch Awe's water level showed almost no variation despite the ongoing operation of Cruachan 1, as shown by the water level variability in Cruachan Reservoir.

Figure 6**Error! Reference source not found.** shows water levels within Loch Awe responding to rainfall events on the 17th and 23rd May 2020, but not to the strong net abstraction from Loch Awe that resulted in a rise in water levels within the Cruachan Reservoir between the 22nd and 24th May.

3.2 Statistical Analysis

Statistical analysis has been used to demonstrate that the observations from the timeseries apply to the whole data period. Daily water level data for Loch Awe are held from 2013 to 2020; daily abstraction returns by Cruachan 1 (including the pumping and power generation flows) are held from 2014 to 2020; and rainfall data are held from 2017 to 2020 (inclusive in all cases). The following analysis is based on the period of overlapping data, covering the four years from 2017 to 2020 inclusive.

It is possible to show from statistical analysis that the operation of Cruachan 1 probably has negligible influence on water levels within Loch Awe, compared with natural rainfall-runoff inputs (and possibly the controlling influence of the Loch Awe Barrage). Figure 7**Error! Reference source not found.** shows the linear regressions between water level and the previous 7 days' accumulated rainfall and between water level and the previous 7 days' net inflow from the power station (in both cases, the correlation is best – that is, R^2 is highest – when taken against the previous 7-day accumulations rather than a longer or shorter accumulation period). There is a much stronger correlation with rainfall and there is not a significant statistical relationship between water level and the power station operation.

The statistical correlation between rainfall and Loch Awe water level is considered significant, even though a R^2 of0.48 would be a relatively low value for R^2 in other contexts. 7-day accumulated rainfall has been used in an attempt to account for the natural lag between rainfall events and increases in loch water level (the topographical catchment area of Loch Awe is relatively large and there will be a delay between rainfall events and upturns in water level). Only data on total rainfall accumulations were available for this study. Not all rainfall events result in the generation of rainfall-runoff. Runoff within the Loch Awe catchment will only occur after soil moisture deficits have been replenished. The use of Hydrologically Effective Rainfall would be expected to generate a higher R^2 value, although these data are currently unavailable. Water levels on Loch Awe are also modulated by the Loch Awe Barrage; this influence may also help to explain the R^2 value.

Ideally, the daily water level change would be compared against net inflows from the pumping station within a shorter period, because over 7 days, the inflows and outflows from the power station would tend to cancel out. However, there are no midnight water level readings from Loch Awe as there are for Cruachan Reservoir (in fact, the timings of the readings are not given for Loch Awe), so this is not feasible. Nonetheless, there are enough occasions where there is a significant positive or negative accumulation of flow from Cruachan 1 (this can be seen in the distribution in Figure 7) to give confidence that water level is not noticeably influenced by the power station's operation.

If water levels within Loch Awe were significantly influenced by the operation of Cruachan 1, then the near-weekly cyclicity in water levels within Cruachan Reservoir (described above) would be mirrored in the daily water level series on Loch Awe.

This analysis can also be placed into context through a simple calculation. The Cruachan Reservoir has a total available volume of approximately 7 million m^3, the Loch Awe surface area is approximately 38km^2, within which the water level gradient is reasonably flat (controlled largely by the Loch Awe Barrage). If the total volume of the Cruachan Reservoir was released into Loch Awe (in the absence of any natural inflows or outflows on the loch), this would result in a water level rise of approximately 220mm.

3.3 Water Velocity

The instantaneous flow capacity of replaced Units 3 and 4 will be slightly greater than the original units, allowing water to be transferred from Loch Awe to the Cruachan Reservoir at a marginally greater rate than has occurred to date, although this is highly unlikely to cause additional scour or morphological damage to the bed and banks of Loch Awe.

3.4 Conclusion

Given that there is no significant water level response within Loch Awe to the current operation of Cruachan 1, even at a water level monitoring point close to the inlet/outlet point, it is reasonable to conclude that the Cruachan 1 Unit 3 and 4 replacement will not result in a discernible impact on Loch Awe water levels. This is because the main impact of the proposed development will be to increase the rate of level rise and fall within the Cruachan Reservoir, rather than increase its storage volume and thus total volume abstracted from, and discharged back to, Loch Awe. The proposals do not involve an increase in the overall volume of water abstracted from Loch Awe to Cruachan Reservoir, and no alteration to Drax's existing abstraction license is sought. As such, the proposed upgrade to Cruachan 1 is not expected to impact water resource availability within Loch Awe.

4 Impact on Private Water Supplies

Existing private water supplies within 5km are located as shown on Figure 8.

During the construction phase, where two existing units will be replaced within the Turbine Hall, there will be no physical impact on any existing private water supplies within the area.

During operation, as concluded above, the impacts on the hydrological regime will be that:

- the instantaneous flow capacity of replaced Units 3 and 4 will be slightly greater than the original units, allowing water to be transferred from Loch Awe to the Cruachan Reservoir at a marginally greater rate than has occurred to date;
- there will be no discernible impact on Loch Awe water levels;
- the rate at which water levels within Cruachan Reservoir could rise and fall in the future would be more rapid than at present; and
- the minimum operating level of the Reservoir will be reduced by 2m from the current minimum 377mAOD to 375mAOD.

During operation there will be no discernible change to the hydrological regime which currently serves existing private water supplies within 5km of the application site.

5 Figures

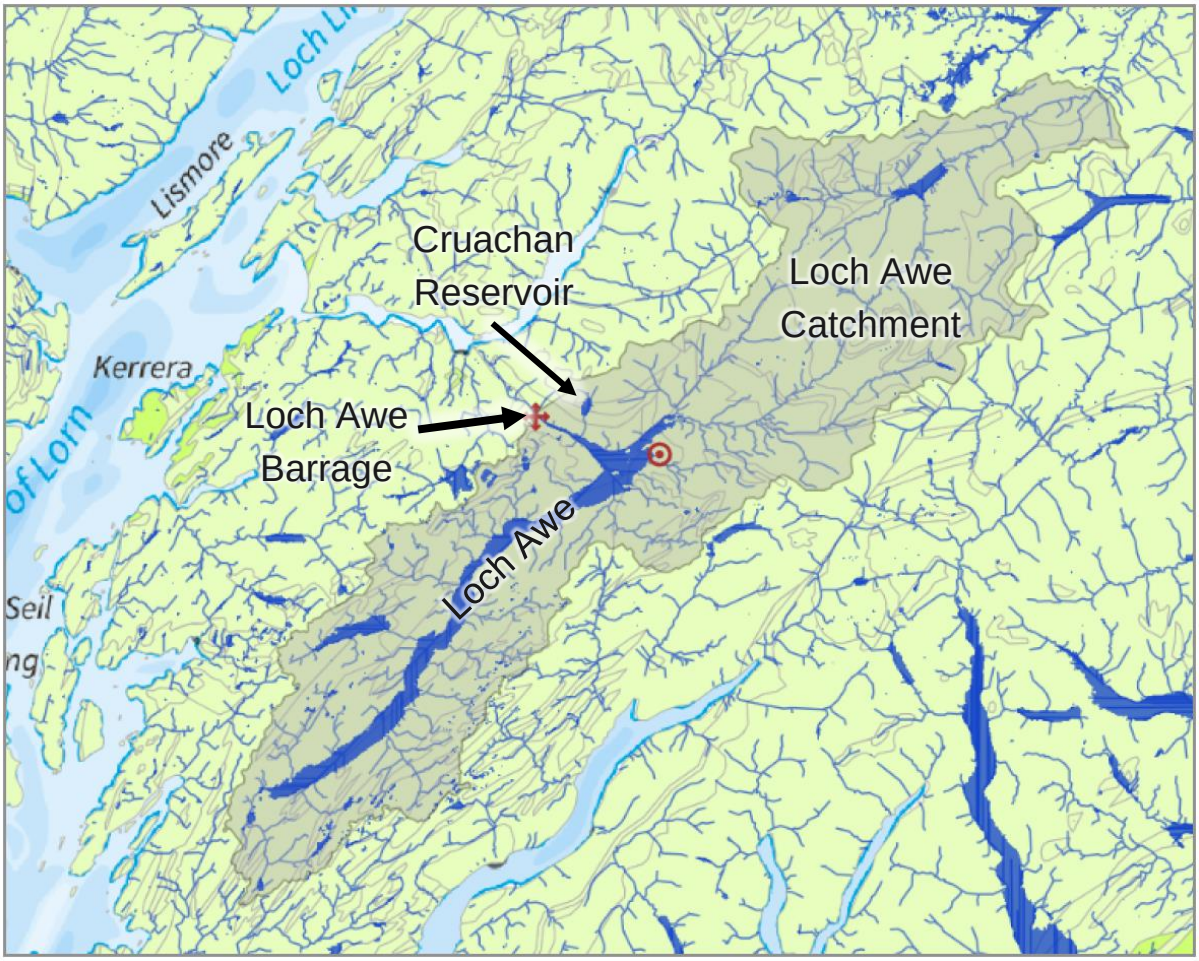
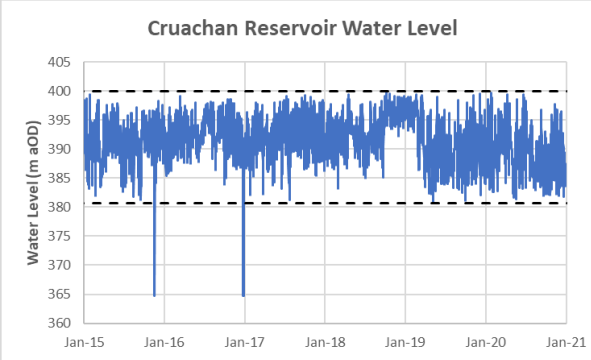


Figure 1: Cruachan Reservoir and Loch Awe setting

Whole Data Period



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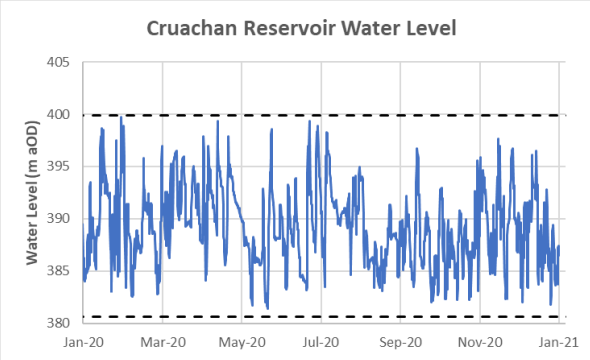
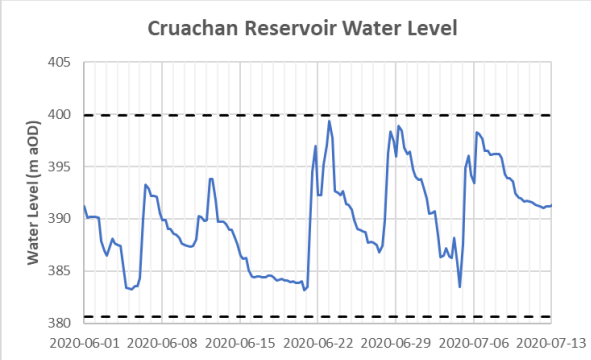
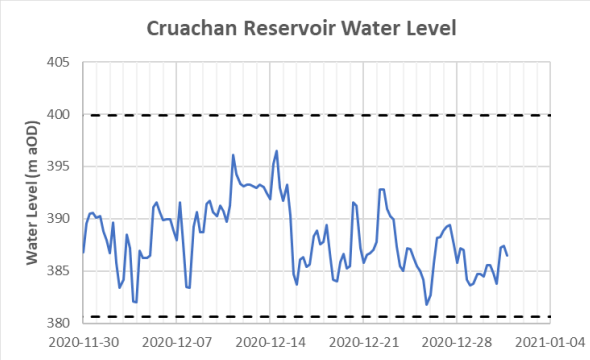


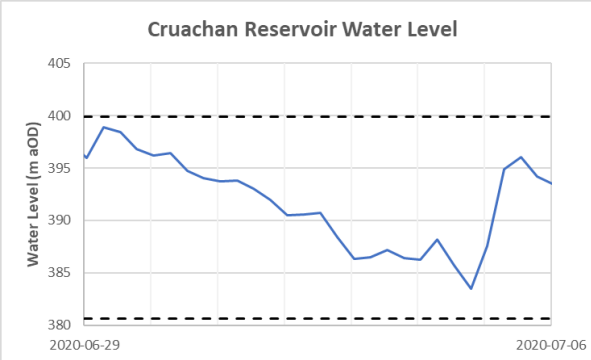
June 2020[1]



December 2020[1]



Example week in June 2020[1]



Example week in December 2020[1]

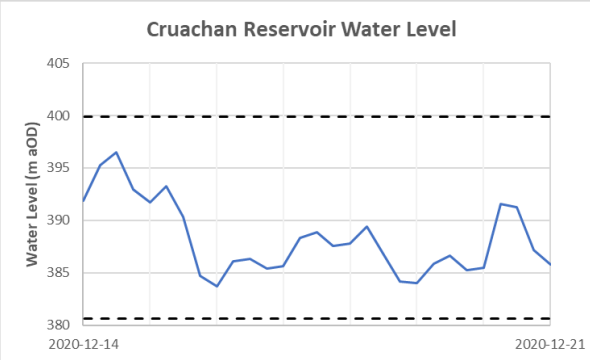


Figure 2: Cruachan Reservoir Water Level Timeseries plots

1. The 1-week and 1-month plots each start on a Monday, with gridlines marking days.

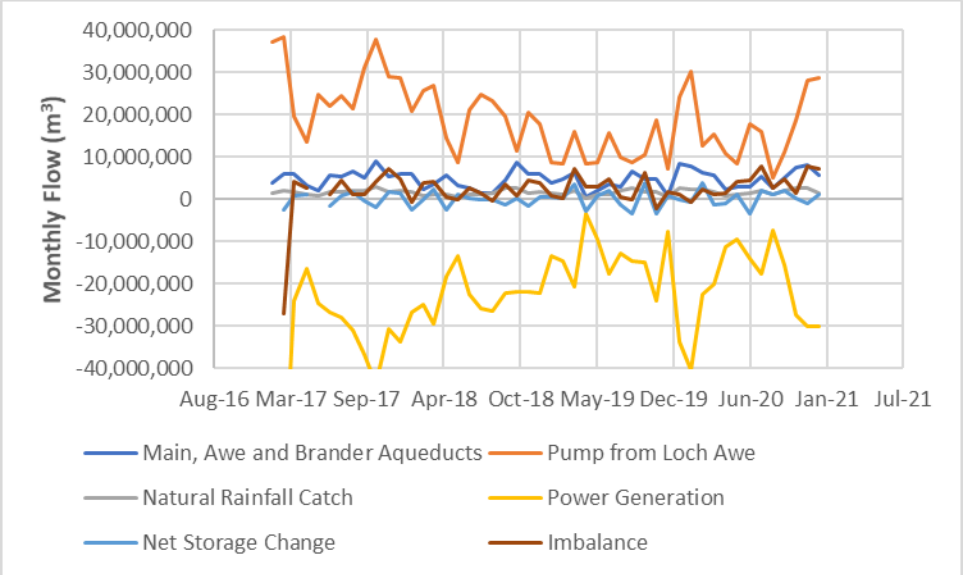


Figure 3: Cruachan Reservoir Monthly Water Balance

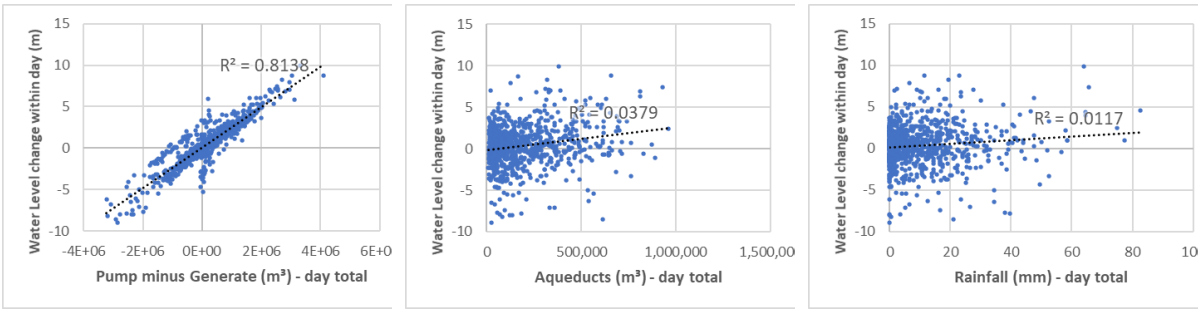


Figure 4: R^2 Analysis of Cruachan Reservoir Water Level against Preceding Flow Components

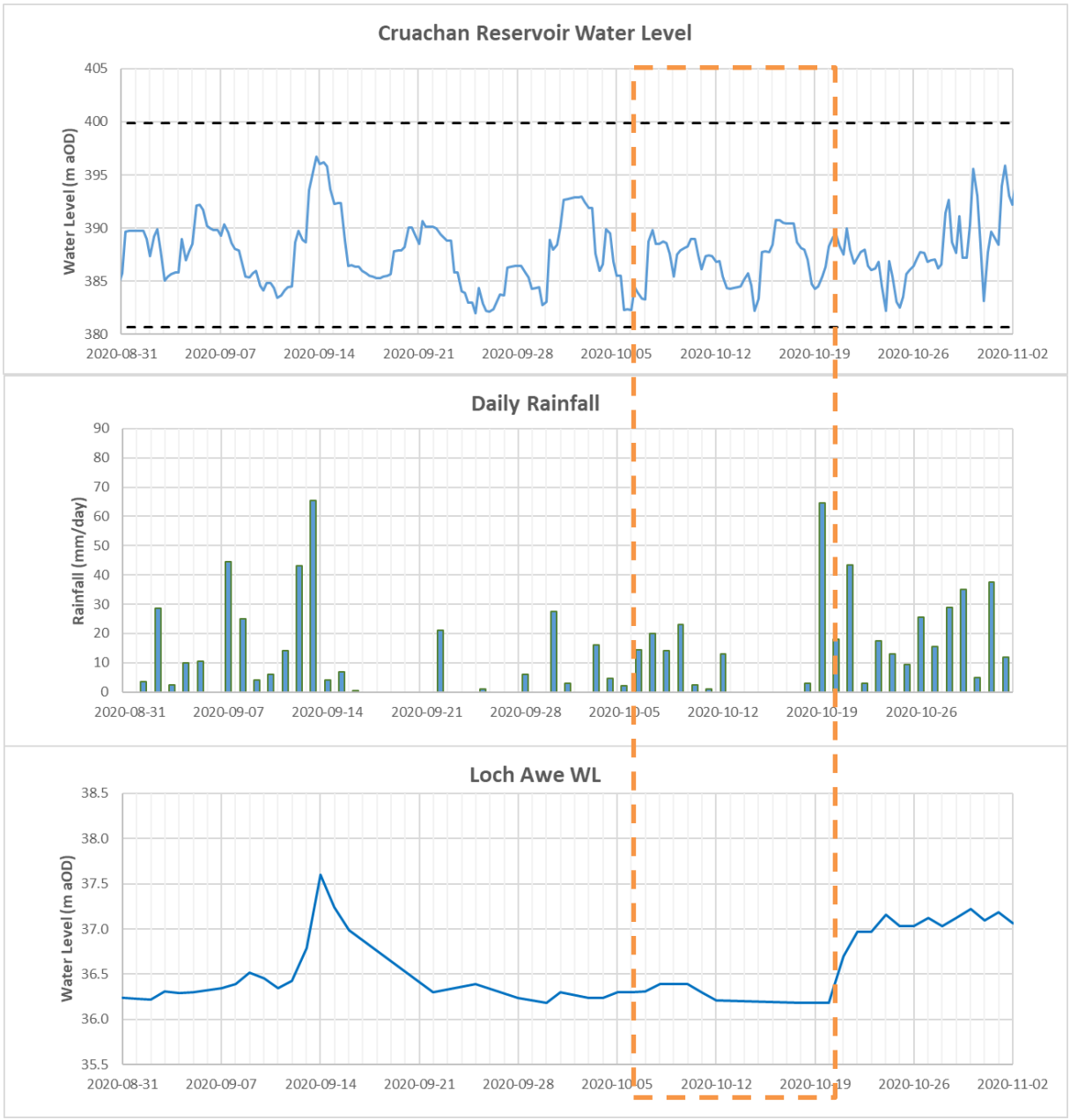


Figure 5: Loch Awe Water Level compared to Rainfall and Cruachan Operation, Sep to Oct 2020

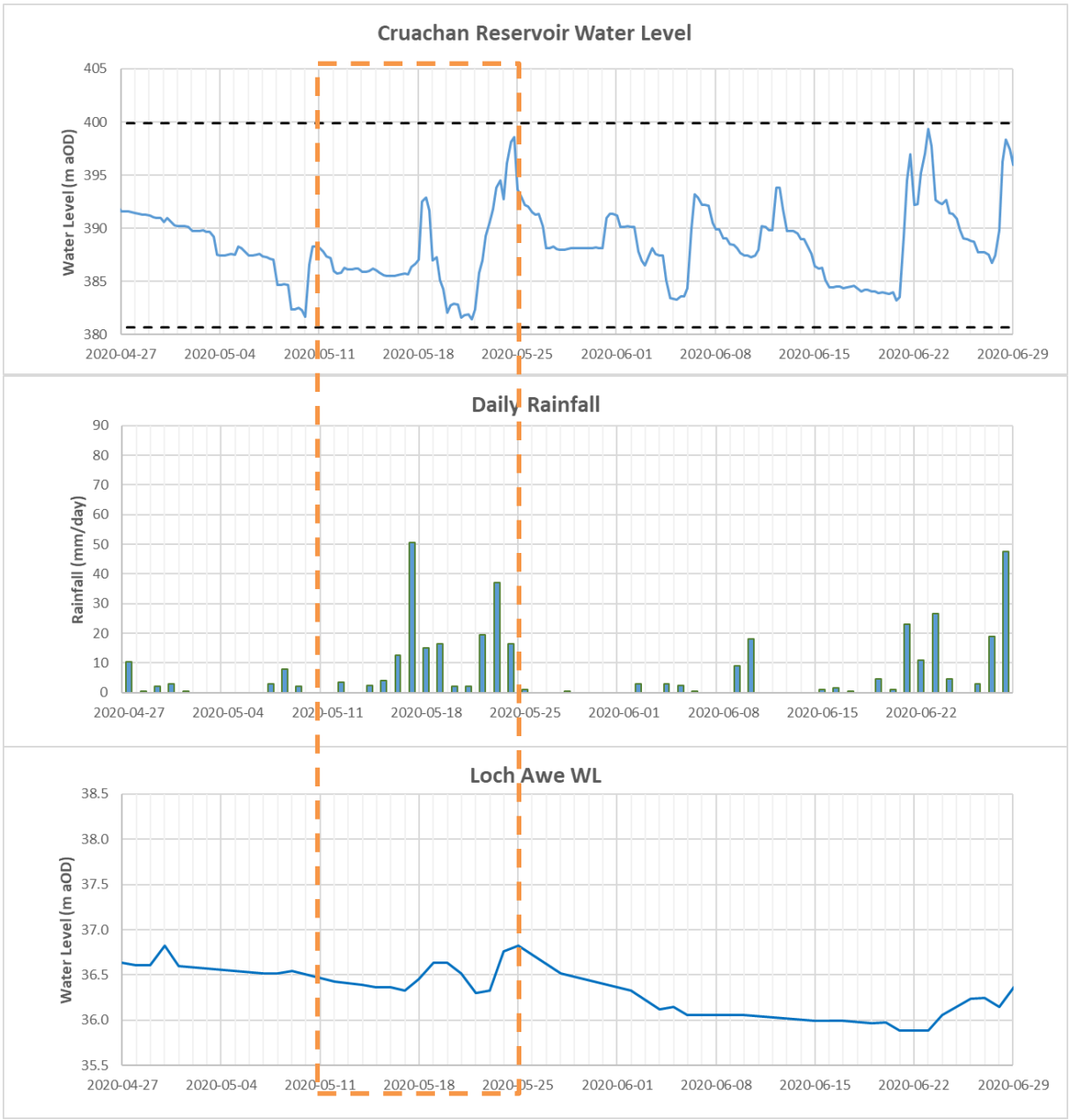


Figure 6: Loch Awe Water Level compared to Rainfall and Cruachan Operation, May to June 2020

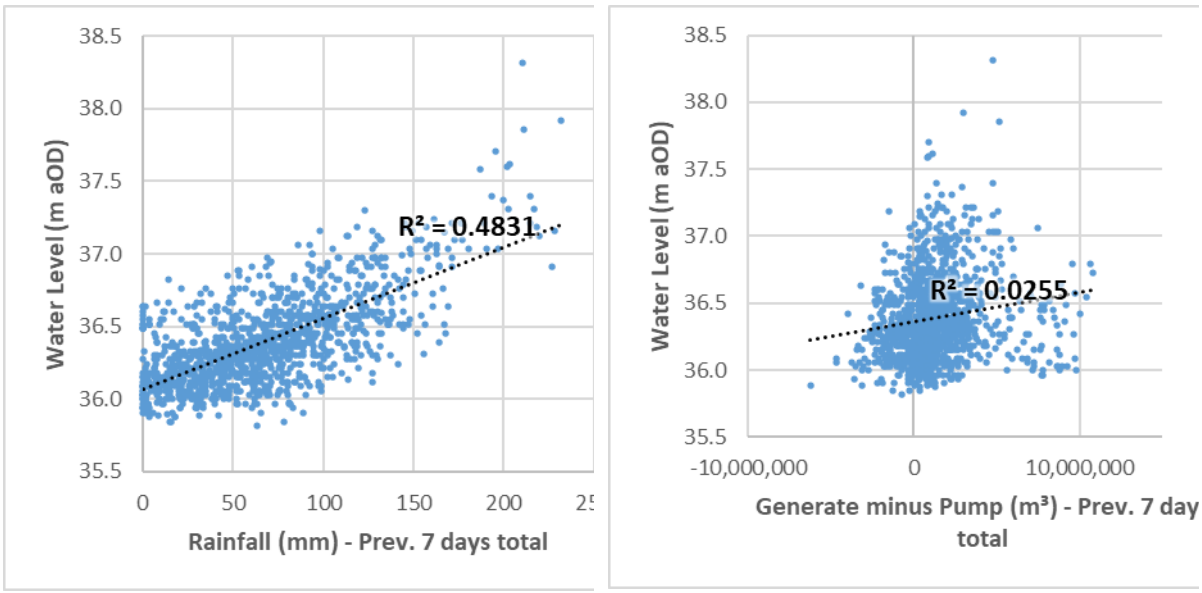
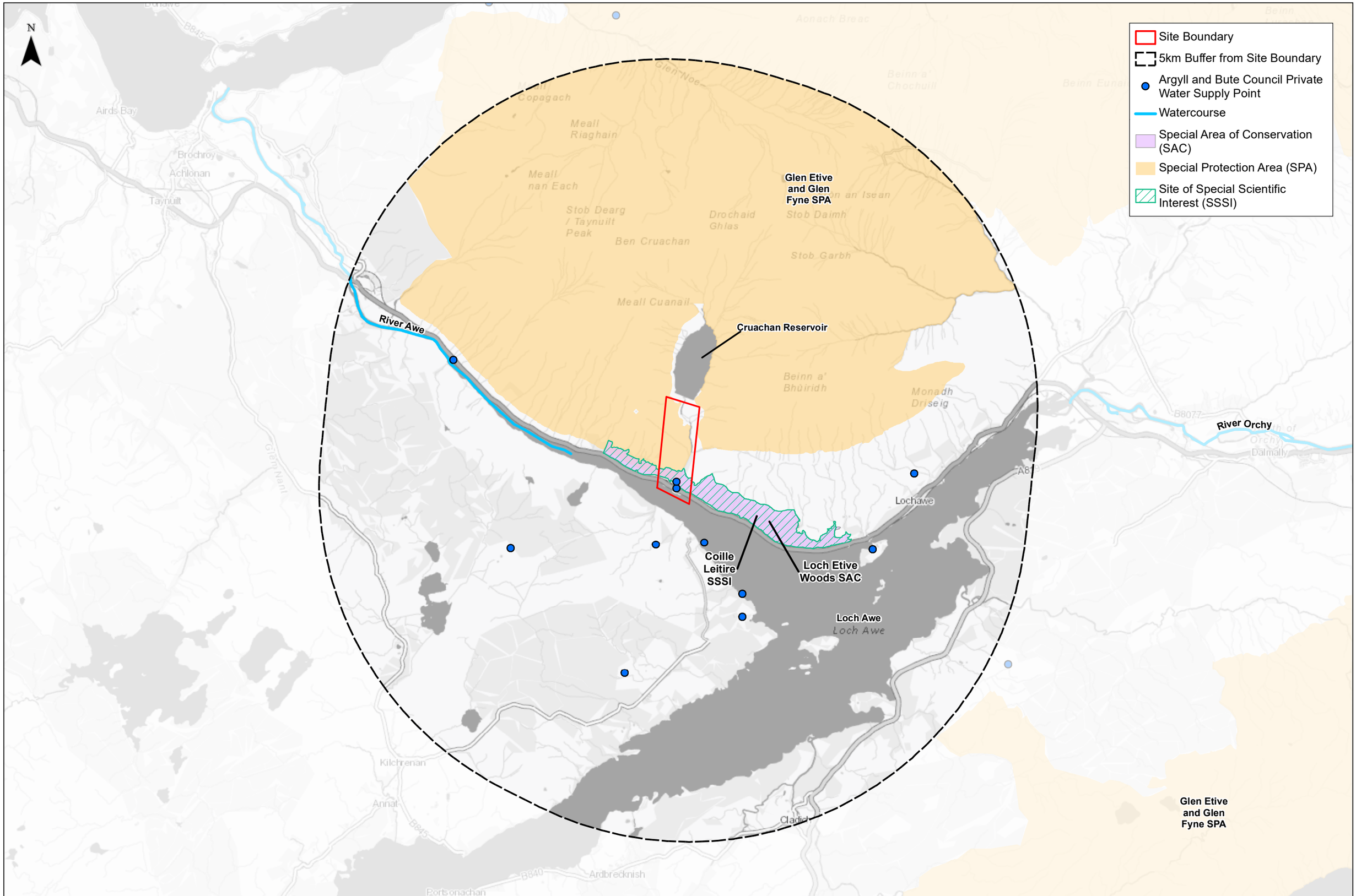


Figure 7: Correlations between Loch Awe Water Level and 7-day Flow Accumulations

Figure 8: Private Water Supplies Within 5km



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