Appendix 7.1

Technical Note on Understanding Water Level Fluctuations in Loch Awe

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Cruachan Expansion Project: understanding likely scheme impact on water levels within Cruachan Reservoir and on Loch Awe

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 ca. 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 ca. 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 watercourses in adjacent catchments (this is discussed further below).

ENVIRONMENTAL IMPACT ASSESSMENT

Drax is planning to construct a new underground power station, Cruachan 2, which will provide greater power generation capacity (600 MWe) when compared with the existing power station (440 MWe). Although Cruachan 2 will be separate from the existing power station, it will use Loch Awe for abstraction and the Cruachan Reservoir for storage and generation, and as such the principles of its operating regime will be similar to that of Cruachan 1. The proposals for Cruachan 2 do not involve increasing the maximum storage capacity currently available within the Cruachan Reservoir or increasing the storage volume available within Loch Awe.

The proposal for Cruachan 2 has, however, triggered the requirement for an Environmental Impact Assessment (EIA). The impact of the scheme on the water environment has been scoped in as part of the EIA. The water environment chapter of the EIA will, therefore, need to consider the impact of the Cruachan 2 scheme on: water resources; the potential for pollution of the water environment; and flood risk.

OBJECTIVES

The objective of this Technical Note is to establish the impact that Cruachan 2 will have on water resources. Specifically, the impact that the scheme will have on water level variability within Cruachan Reservoir and on 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 Cruachan 2 scheme has, therefore, been assessed within the context of these causal mechanisms and water level interdependency.

IMPACT ON WATER LEVELS WITHIN CRUACHAN RESERVOIR

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 2 in place, overall power generation will increase from 440 to 1040 MWe. As power generation is directly related to the rate and volume of water discharge, this means that the combined existing and proposed power stations will be able to drain and fill Cruachan Reservoir more quickly than at present.

Cruachan Reservoir has an operational water level range of between 378m AOD and 399.90m AOD (maximum operational level); this is a maximum water level range of approximately 20m. 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 and minimum operational water level boundaries will be maintained with Cruachan 2 in place.

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 thought to be significant by comparison).

Timeseries Analysis

Drax has provided a time series of water levels within the Cruachan Reservoir from 2015 to present. 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.

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 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.

[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.

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).

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 operational range (i.e. between 378 and 399.90m 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 for power generation), and not significantly influenced gravity inflows from the aqueducts or by natural rainfall-runoff.

The operational water level range within the reservoir will not change with the Cruachan 2 scheme in place. Similarly, the proposals for Cruachan 2 do not involve increasing the maximum storage capacity currently available within the Cruachan Reservoir or increasing the storage volume available within Loch Awe.

The principal impact of the Cruachan 2 scheme will be that the rate at which water levels within the reservoir could rise and fall in the future could be more rapid than the significant water level dynamics shown in Figure 2 above. The maximum and minimum operational water levels that would be achieved with Cruachan 2 in place would, however, be constrained within the reservoir's 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 with Cruachan 2, with artificial factors already being dominant over naturally driven variation.

IMPACT ON WATER LEVELS ON LOCH AWE

Loch Awe is impounded by the Loch Awe Barrage. The barrage is operated by Scottish and Southern Electricity (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.

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.

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.

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 0.48 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 ca. 7 million m^3. The Loch Awe surface area is ca. 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 ca. 220mm.

Water Velocity

In terms of water velocity at the proposed Cruachan 2 intake (which will also be the new outlet when generating), the new smolt screens have been designed such that maximum velocities through the screens will not exceed 0.3 m/s; a velocity that is unlikely to cause additional scour or morphological damage to the bed and banks of Loch Awe.

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 Cruachan 2 will not result in a discernible impact on Loch Awe water levels. This is because the main impact of Cruachan 2 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).

FIGURES

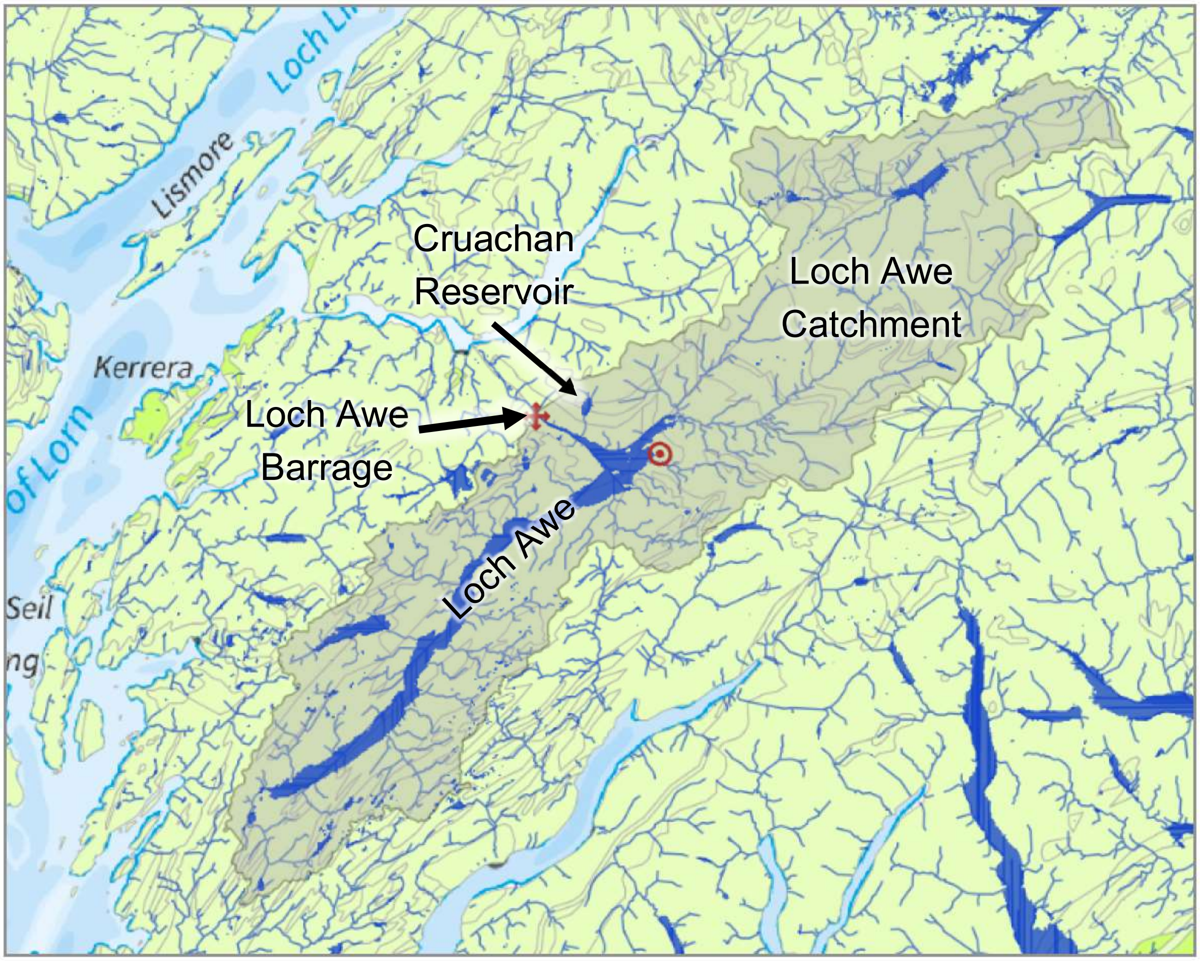
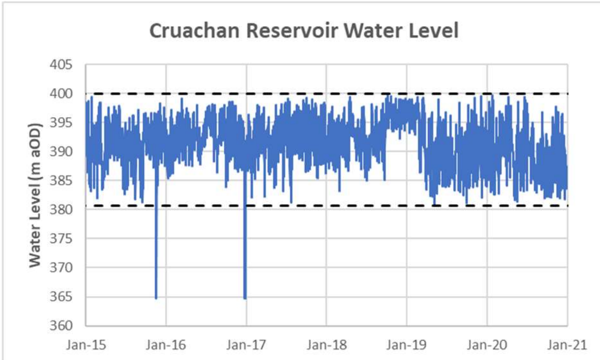
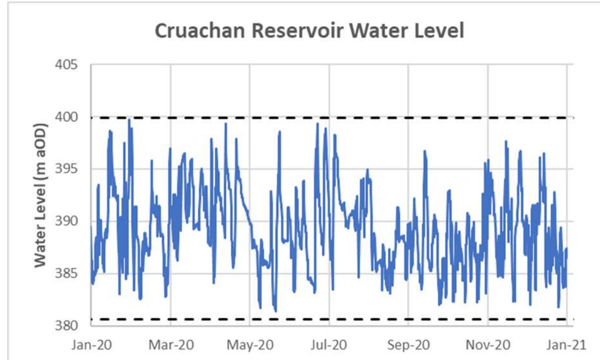


Figure 1: Cruachan Reservoir and Loch Awe setting

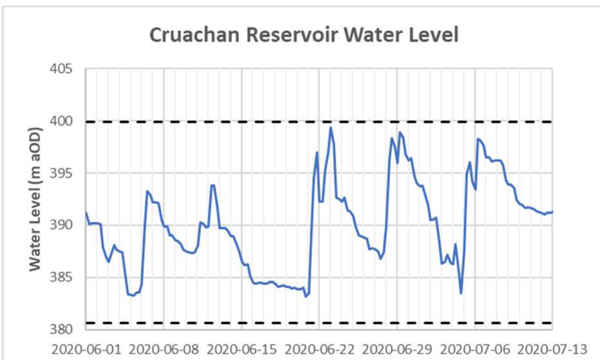
Whole Data Period



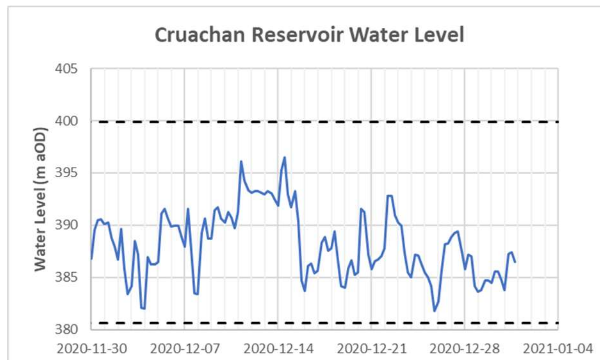
2020



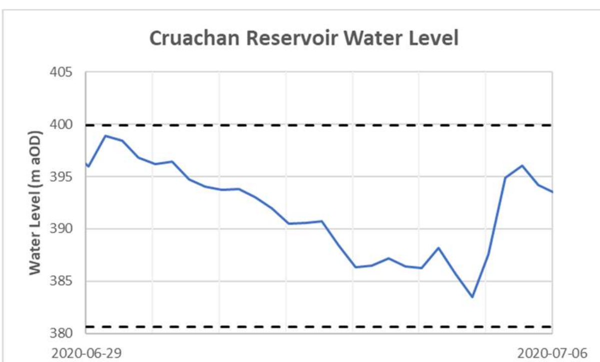
June 2020[1]



December 2020[1]



Example week in June 2020[1]



Example week in December 2020[1]

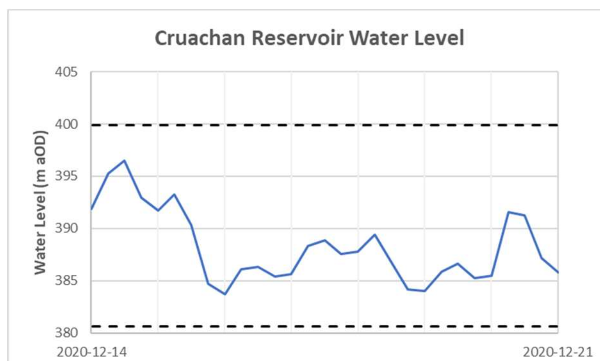


Figure 2: Cruachan Reservoir Water Level Timeseries plots

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

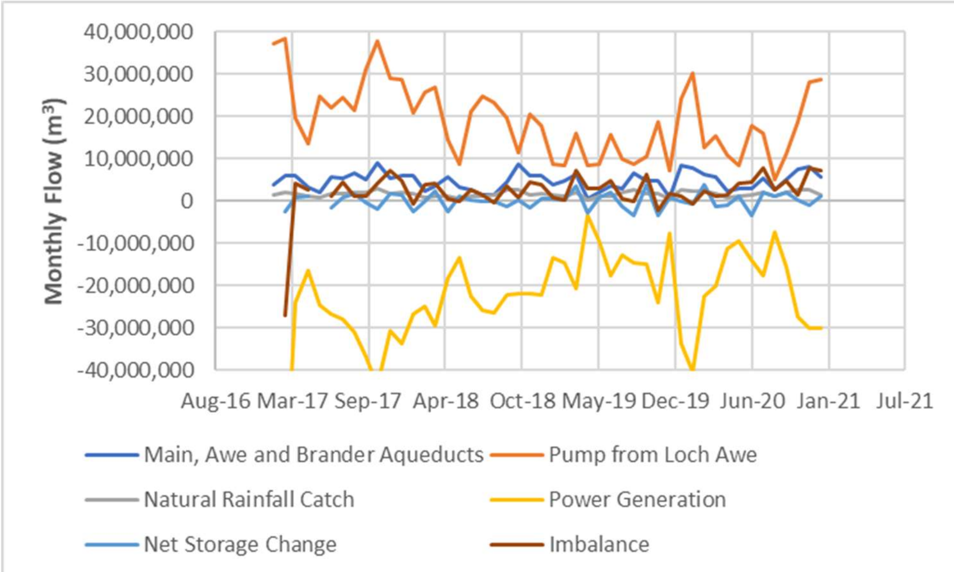


Figure 3: Cruachan Reservoir Monthly Water Balance

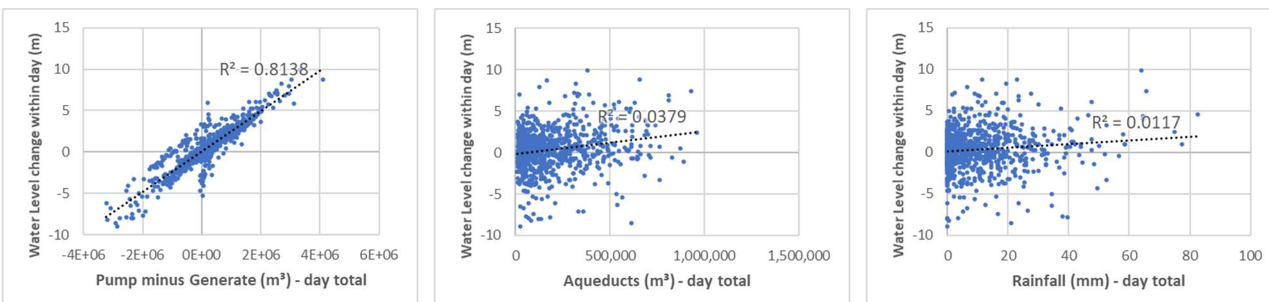


Figure 4: R^2 Analysis of Cruachan Reservoir Water Level against Preceding Flow Components

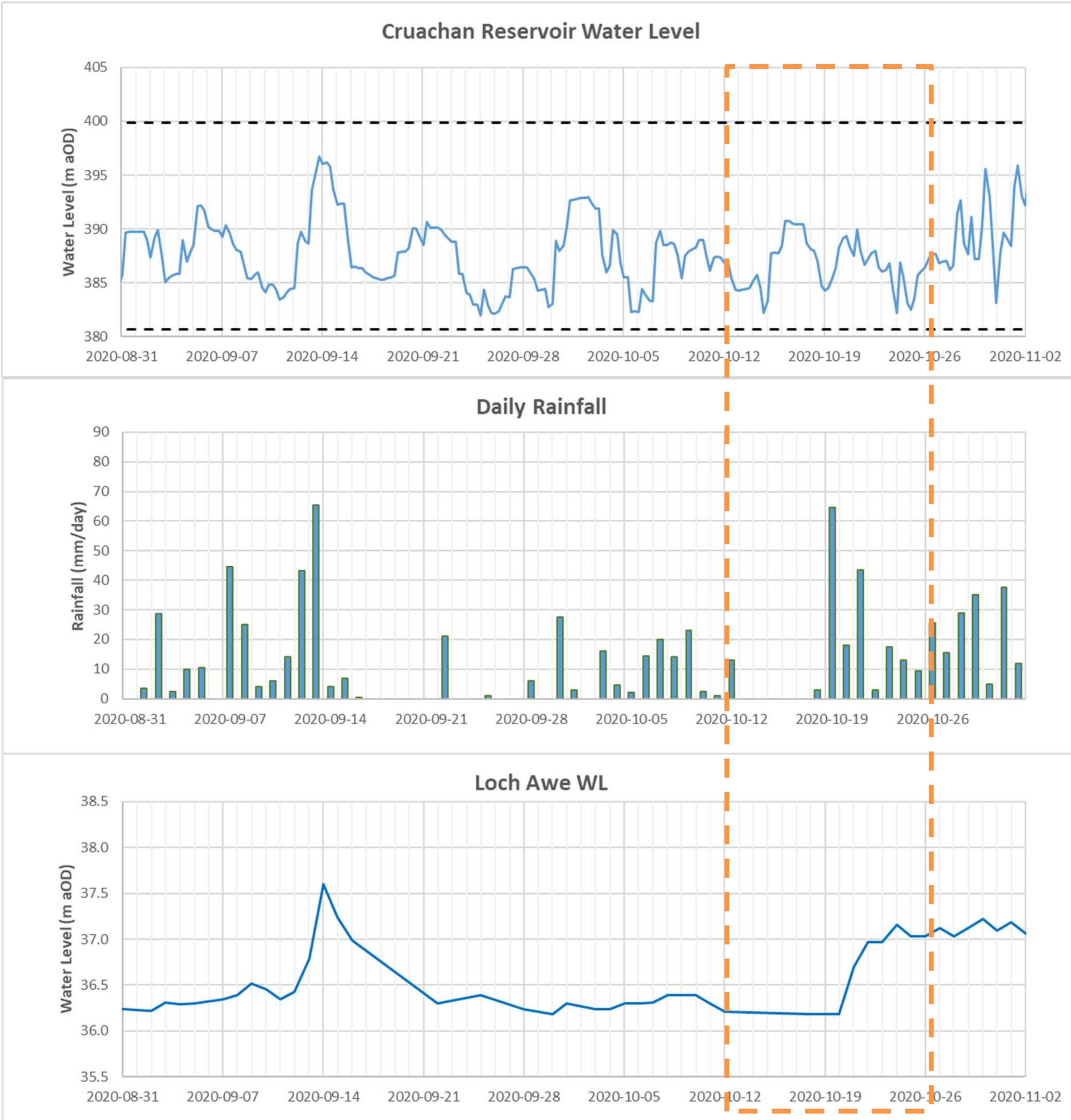


Figure 5: Loch Awe Water Level compared to Rainfall and Cruachan Operation, September to October 2020

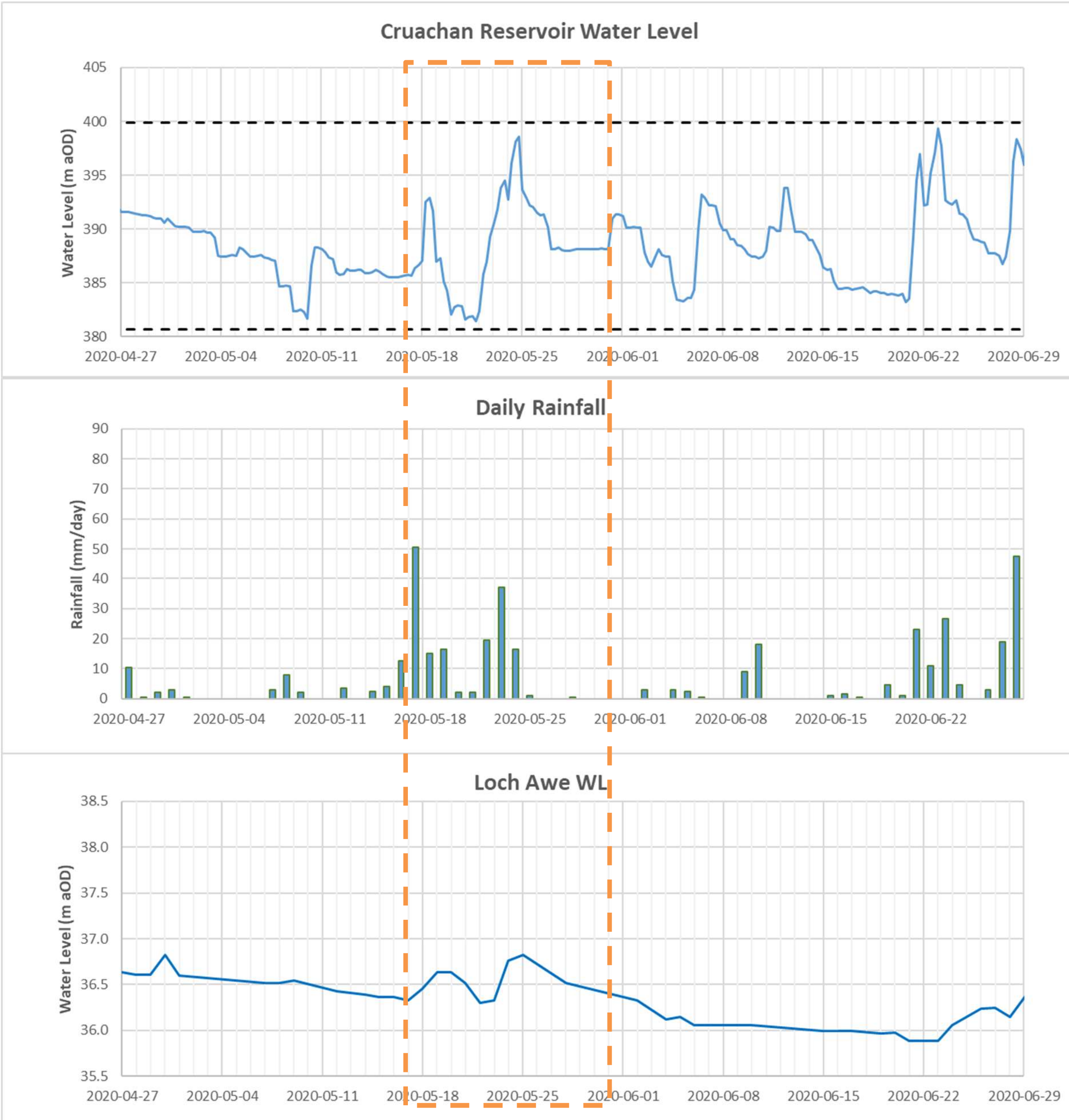
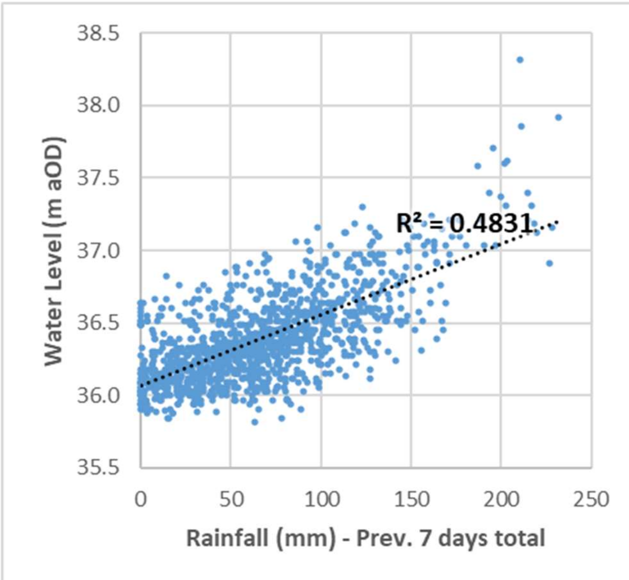


Figure 6: Loch Awe Water Level compared to Rainfall and Cruachan Operation, May to June 2020



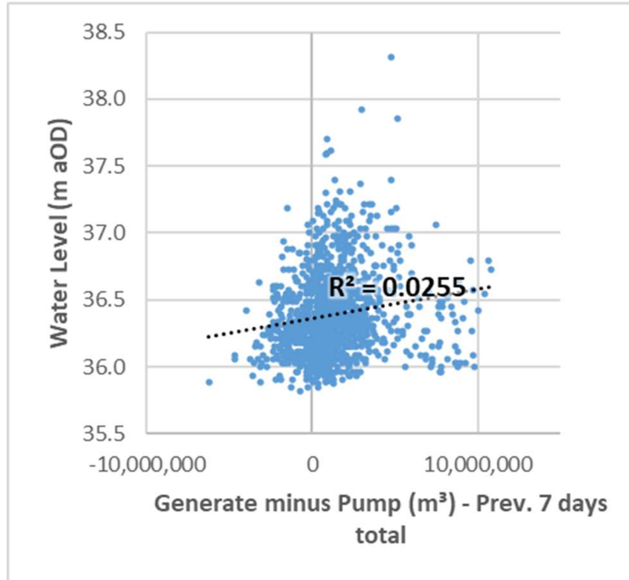


Figure 7: Correlations between Loch Awe Water Level and 7-day Flow Accumulations