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NOTE

Estimating Teviot River compensation flow to offset evaporation loss from Lake Onslow pumped storage

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Abstract

Lake Onslow in New Zealand's Central Otago region is under consideration for a major expansion to become the upper reservoir of a significant pumped storage scheme with 5 TWh energy storage capacity. The increased evaporation loss would likely lead to a requirement for compensation input of new water to the lake to maintain its mean outflow to the Teviot River. A simple expression is obtained that gives an upper bound of 1.5 m^3s^{-1} for compensation flow if the lake is expanded to 60 km^2. The compensation water could be derived from the pumping operation at the expense of some energy loss. Alternatively, water input without energy loss might be achieved by diverting some flow into Lake Onslow from the nearby Taieri River.

Keywords

lake evaporation; Onslow pumped storage; catchment water yield; compensation flow; Taieri River.

Introduction

The energy storage potential of the Lake Onslow basin has been known for some time, whereby a considerably expanded Lake Onslow could be the upper reservoir of a pumped storage scheme (Bardsley, 2005). Raising Lake Onslow is currently (2022) under investigation by the New Zealand government as a buffer against future dry years when the country has transitioned to 100% renewable electricity.

The national goal for a dry year buffer is to have 5 TWh of additional energy storage capacity (Ministry of Business, Innovation and Employment, 2020). This would almost double New Zealand's current hydroelectric power storage capacity. The additional storage could be achieved at Lake Onslow by a considerable expansion of the lake coupled with a large operating range.

The large free-water surface would cause additional evaporation loss and there would likely be a requirement for a compensation input of new water to maintain the Teviot River mean outflow from the lake. The extent of the necessary compensation flow may have energy implications and it is of interest to have an indication of the likely flow involved. This brief communication gives a simple expression for an upper bound to the additional Teviot River flow needed to compensate for evaporation loss.

Hydrology

Precipitation varies spatially over the Teviot River catchment, with Lake Onslow located midway between a drier region to the north and a wetter zone in the higher uplands to the south (Macara, 2015). Annual precipitation in the wetter zone has been estimated at 1–1.2 metres (Duncan and Thomas, 2004). A rain gauge (NIWA site reference I59562) was operational for the period 1986–2013 near the Teviot River outlet from Lake Onslow. There are 16 years in this record that have no more than 5 missing days of data. The mean annual precipitation derived from these years is 0.6 metres, with a standard error of 0.01 metres. Calculation of the standard error is justifiable in this case because there is no evident trend or serial correlation present. NIWA does not adjust recordings to allow for possible gauge catch reduction due to winter snow effects, so the actual mean precipitation at the site may be a little higher than 0.6 metres.

For the purposes of the present study, the Teviot catchment (Fig. 1) is defined to be the 229 km^2 drainage basin upstream of the Bridge Huts Road recording station, operational since 1994. The catchment comprises mostly grazed tussock hill country with some conversion to pasture grasses. Lake Onslow takes up less than 4% of this catchment area.

There are 20 years of flow record that have less than 5 days of missing data. These years collectively give a mean discharge of 3.7 m^3s^{-1}, equivalent to a Teviot catchment annual water yield of 0.51 metres. There is controlled seasonal water release from Lake Onslow but there is no evident serial correlation for the 20 annual mean flows and no evidence of a trend. On the basis of independent annual flow means, the standard error of the mean flow is 0.1 m^3s^{-1}.

There are no direct evaporation measurements available from Lake Onslow. An upper bound to its evaporation loss can be obtained by considering regional pan evaporation values. As noted by Stewart (2012), pan evaporation in Otago is lower at higher altitudes due to lower temperatures.

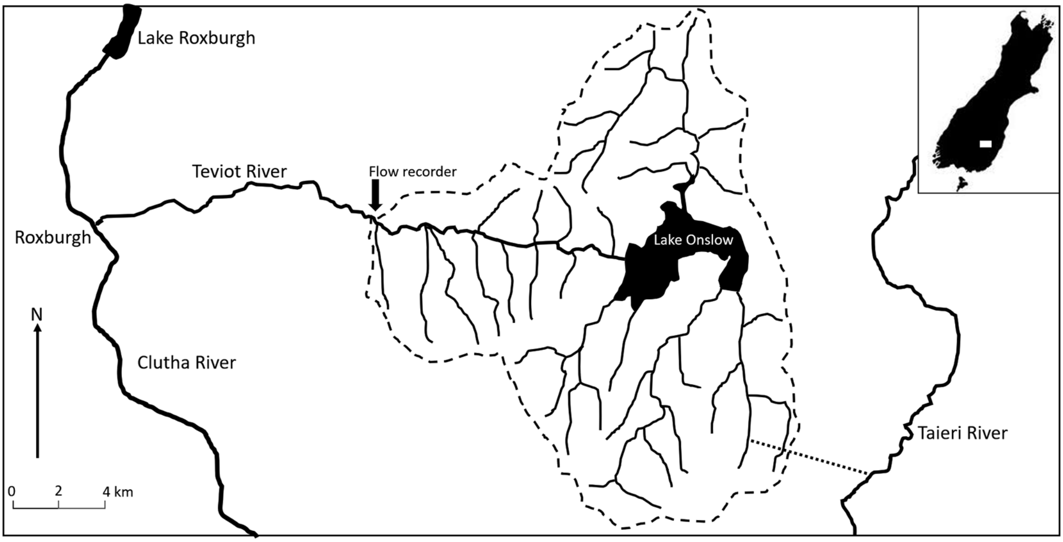

Figure 1 – Lake Onslow and the Teviot River catchment (dashed line) upstream of the Bridge Huts Road flow recording site (vertical arrow). The dotted line is a possible tunnel location for transfer of water from the Taieri River to the Lake Onslow basin (see text).

In that study, evaporation from the Falls Reservoir (elevation 570 metres) was estimated from a sunken evaporation pan at Tara Hills (488 metres elevation) in eastern Otago. We took a similar approach to obtain an upper evaporation bound for Lake Onslow (684 metres elevation). We applied a pan coefficient of 0.8 to the Tara Hills mean annual pan evaporation estimate of 1.179 metres (Stewart, 2012) to obtain a Lake Onslow upper evaporation bound of 0.9 metres. The upper bound nature of this value derives from not making an adjustment for Lake Onslow's higher elevation, which will lead to lower evaporation compared to Tara Hills.

Magnitude of Lake Onslow expansion

Details of the proposed extent of Lake Onslow expansion should be made public later in 2022, if a decision is made to proceed with the pumped storage scheme. In the meantime, it is possible to make an informed estimate of an upper bound to the size of the expanded lake.

If pumped storage is selected as the mechanism for dry year reserve, then the full 5 TWh is likely to be located at Lake Onslow. This is because splitting over multiple schemes would require multiple consents and engineering evaluations, which would add considerably to the total cost and construction time.

Assuming there would be 5 TWh energy storage capacity at Lake Onslow, the maximum lake level elevation is likely to be as low as possible to minimise submerging existing stream channels. The constraint here is that the maximum level should not be so low as to re-expose former wetlands as extensive mudflats if the lake is lowered to its minimum level.

On these arguments, the 5 TWh storage capacity would be achieved by a lake operating range between 700 and 765 metres elevation. This is based on the Majeed (2019) elevation/energy relation for Lake Onslow, which might be refined later by LiDAR studies as part of site investigations. The 765-metre lake elevation corresponds to a lake surface area of approximately 60 km^2, which is used here in the compensation flow upper bound estimate. The bound can be adjusted downward if a smaller maximum lake surface area is proposed.

Whatever the upper operating level selected, an expanded Lake Onslow would seldom be at that level because the pumping option would then not be available.

Estimating an upper bound to compensation flow

For an expanded Lake Onslow that occupies a proportion, p, of the Teviot catchment area, the catchment annual water yield can be written as the weighted mean of two water yields:

$$Y = pY_1 + (1 - p)Y_2 \qquad (1)$$

where Y_1 is the water yield of the lake and Y_2 is the water yield of the land component of the Teviot catchment.

An assumption here is that Y_1 and Y_2 are constants independent of p. Given the relative uniformity of the catchment, this is probably reasonable for Y_2. Even for a lake area of 60 km^2, the land component still comprises 74% of the catchment area, limiting the possible variability of Y_2 with p.

A second assumption is that the spatial mean of the difference between lake rainfall and lake evaporation is independent of the size of the lake, up to a lake area of 60 km^2.

For given p, a lower bound to the water yield Y is obtained by replacing Y_1 and Y_2 in Equation 1 with lower bounds for those quantities. For Y_1, the utilised lower bound is -0.3 metres (0.6 minus 0.9 metres), utilising the 0.9-metre upper bound to lake evaporation. The lower bound for Y_2 is the recorded catchment water yield of 0.51 metres. The bound applies here because the 0.51 value includes a component of reduced water yield from the present Lake Onslow.

The lower bound, Y_B, for Y is thus obtained for given p as:

$$Y_B = -0.3p + 0.51(1 - p) \tag{2}$$

An upper bound, ΔY_U, to the annual water yield reduction is given by:

$$\Delta Y_U = 0.51 - Y_B \tag{3}$$

A p value of 0.26 (60 km^2 lake area) gives ΔY_U = 0.30 metres per year. From the catchment area of 229 km^2, this translates to an upper bound of 1.5 m^3s^{-1} for the evaporation compensation discharge. If the scheme proceeds, its specified maximum lake area will enable an adjustment of the upper bound through use of a different p value.

Discussion and conclusion

There is an implication of energy loss if the compensation flow is achieved by pumping more water, on average, than is returned during generation phases of the pumped storage scheme. The amount of energy loss will depend on lake level elevation and pumping efficiency. Pumping 1.5 m^3s^{-1} from the Clutha River below Roxburgh up to Lake Onslow at 87% efficiency would require a power input in the order of 10 MW. This power loss is an upper bound. Whether the actual pumping power required is a relatively important energy component will depend on the frequency of pump generation cycles during the scheme operation. For example, suppose Lake Onslow was operated only in dry year reserve mode with 4 TWh of energy storage used once every 10 years. At 75% cycle efficiency, this would translate to an equivalent of 14 MW ongoing power loss as a time average. Lake Onslow pumped storage would operate in practice over a range of time scales, down to hours.

It would be worth seeking an alternative source of compensation water that did not have energy loss implications. An obvious possibility is to construct a gravity flow tunnel to transfer water to the Lake Onslow basin from the upper Taieri River outside of the irrigation season. For example, a 5.3 km tunnel could link the Taieri River with a Lake Onslow tributary at 860 metres elevation (Fig. 1). There would be various factors to be considered in the consenting process of any Taieri water transfer. In particular, there could be cultural concerns arising from inter-basin water transfer. Also, there would be some reduction in water throughput for the two small Trustpower hydroelectric power stations in the Maniototo.

The 1.5 m^3s^{-1} compensation flow upper bound is qualified by the water yields Y_1 and Y_2 remaining independent of p, as mentioned earlier. This is probably reasonable for Y_2 (the land component) but there is less certainty with regard to the lake water yield component Y_1.

The compensation flow upper bound given here serves as a preliminary value. If the pumped storage scheme proceeds, there will be time during construction to accumulate direct evaporation measurements over several seasonal cycles. Also, additional rain gauges would allow spatial rainfall interpolations with some degree of accuracy. An estimate of the required compensation flow would then become available to incorporate into the pumped storage scheme design and operation.

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