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NOTE

Note on the pumped storage potential of the Onslow-Manorburn depression, New Zealand

W. E. Bardsley
Department of Earth Sciences
University of Waikato

Abstract
The Onslow-Manorburn depression in the South Island of New Zealand has possibility for development as the upper reservoir of the world's largest pumped storage scheme, as measured by an energy storage capacity of 10,200 GWh of realisable potential energy. This would more than triple the total national hydro-power energy storage capacity. It is envisaged that the scheme could either operate on a seasonal cycle or act as a passive energy reserve to buffer existing hydro-power capacity against the effect of dry years.

Introduction
The elongated Onslow-Manorburn depression in Central Otago extends over approximately 25 km in a north-south orientation (Fig. 1). The 800 metre contour defines two adjacent basins within the depression, with a low divide separating the smaller Upper Manorburn basin in the north from the larger and lower Onslow basin to the south. The lowest point in the depression is the Lake Onslow outlet at approximately 700 metres above sea level. This is the same elevation as New Zealand's highest major hydro storage lake (Lake Tekapo), allowing the possibility that the national hydro-power storage capacity could be significantly increased by using one or both basins as the upper reservoir of a large pumped storage scheme. This brief paper presents a quantification of the energy storage capacity of a reservoir of this type in the Onslow-Manorburn depression.

The Clutha River would be the input and exit points of the scheme—hydrological viability was verified using a pumped storage simulation coupled with past Clutha River flow records. These simulations showed that large-scale pumped storage could operate while still maintaining the Clutha River within its normal discharge regime (Bear, 2005). This is because water release for electricity supply tends to coincide with times of low Clutha flow, while river water for pumping would be extracted during times of high flow. At the same time there would be some reduction in lower Clutha flood peaks. These hydrological and operational aspects will be discussed in a subsequent publication.

Energy storage capacity
It is envisaged that the pumped storage scheme would alternately pump and release water through a rock tunnel connecting the Clutha River with the new reservoir in the Onslow-Manorburn basin. Energy calculations are based on the pump-generators being located at 80 metres above sea level, corresponding approximately to the outlet elevation of a 15-kilometre tunnel linking the new reservoir with the Clutha River near Teviot (Fig. 1). However, the energy storage values would be little different for an alternative configuration with a longer 20-kilometre tunnel linking the reservoir to pump-generators at Lake Roxburgh. In this case the height of the

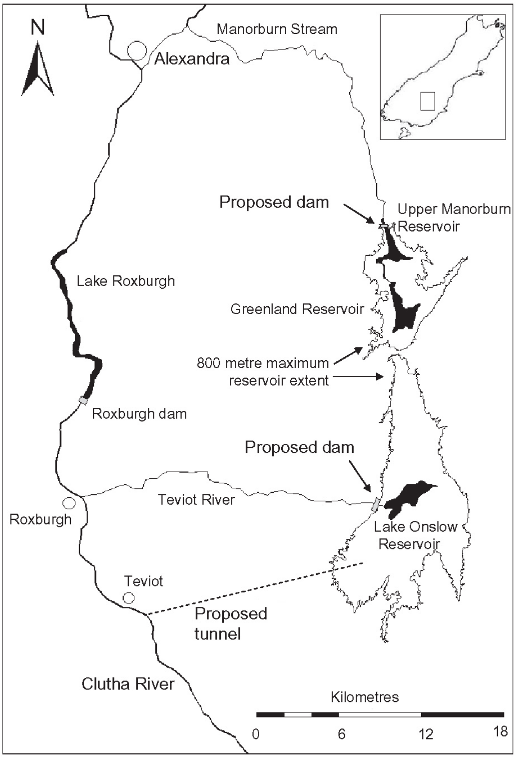

Figure 1 – The Onslow-Manorburn depression, showing maximum pumped storage reservoir development to 800 metre elevation in both Upper Manorburn and Lake Onslow basins.

Roxburgh dam becomes part of the potential energy, although at the expense of some operational flexibility of the station. On the other hand, a Lake Roxburgh entry-release point would reduce Roxburgh dam spillage losses.

The new reservoir could be located entirely within the Onslow basin alone, or the two basins could function as a single reservoir if they were hydraulically connected by a cut or tunnel through the separating divide. The higher elevation of the Upper Manorburn basin means that the two basins could operate as a single storage unit only when the reservoir water surface was above the connection level. At other times the Upper Manorburn reservoir segment would become temporarily isolated.

It would be unacceptable environmentally to allow the operating range of the new reservoir to extend to complete drainage, so the lower operating levels of the Onslow and Upper Manorburn basins were defined respectively to be 720 and 760 metres above sea level. The latter elevation also serves as the level of hydraulic connection through the dividing ridge. The two minimum water levels would be approximately 20 metres higher than the respective current water levels of the existing small Onslow and Upper Manorburn/Greenland reservoirs (Fig. 1).

The reservoir gravitational potential energy can be calculated from the water volume integral between 720 metres and any specified water level up to a maximum of 800 metres. The resulting energy storages are shown in Figure 2 as GWh of potential energy as a function of water level above 720 metres. The single and combined-basin storage options are shown as separate energy storage-elevation relations above 760 metres. The lower line represents Onslow basin storage only, while the upper line shows the inclusion of Upper Manorburn basin storage when there is hydraulic linkage between the basins at 760 metres.

Figure 2 also shows the approximate heights of the dams required to establish the new reservoir for a given maximum operating level. The Onslow-only option would require a single significant earth dam near the present low dam at the Lake Onslow exit. The use of both basins would involve a further dam to be constructed a little south of the present Upper Manorburn dam, at a site presently beneath the existing Upper Manorburn reservoir. A small 10-metre embankment dam along a low ridge would also be required if the new Upper Manorburn reservoir was to be operated up to 800 metres.

If the reservoir was developed to its fullest 12,000 GWh storage, with 85% generation efficiency, the resulting realisable energy storage value of 10,200 GWh would more

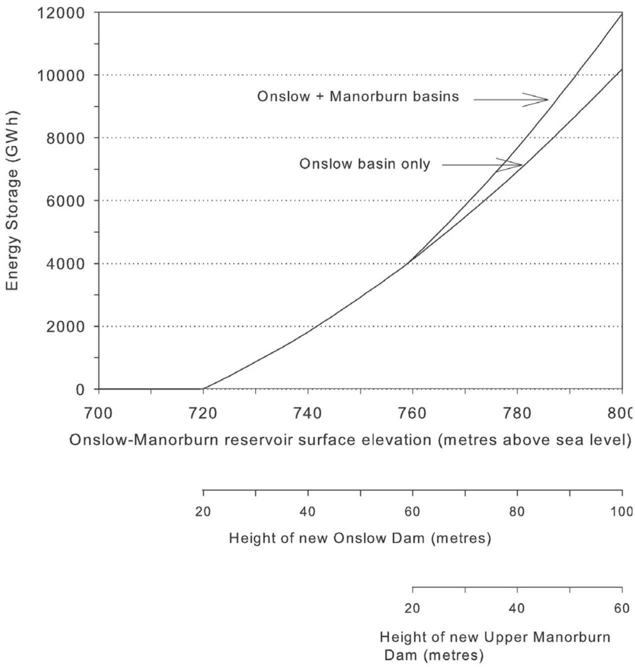

Figure 2 – Gravitational potential energy of a pumped storage reservoir in the Onslow-Manorburn depression. For both dams, the energy storage contribution is measured from zero at a 20-metre dam height on the basis of maintaining a permanent minimum lake area for environmental reasons.

than triple the total national energy storage capacity to 14,400 GWh from the current low value of around 4,200 GWh. An alternative less costly development might be to use the Onslow basin alone and double the national energy storage, with construction of the new Onslow dam to a height of about 70 metres.

One factor in favour of maximum development is the significant incremental storage achieved at higher water levels, as seen by the steepening gradient of the storage-elevation relations in Figure 2. For example, the combined basin energy storage between 780 and 800 metres is almost equal to the present national energy storage capacity.

Energy storage efficiency

Pumped storage is not as efficient as energy storage in a river-supplied hydro lake. This is because there will be inefficiencies in generating the power that is used to pump the water, inefficiencies in the pumping process itself, and inefficiencies when producing power from the pumps run in reverse as generators. However, a large volume of water in a pumped storage lake has the same value for national power supply security at a given time as the equivalent potential energy in existing hydro lakes.

The energy calculations leading to Figure 2 make no allowance for losses in efficiency from any water diversions for alternative use. For example, an arrangement might be made to transfer some water to Deep Stream for Dunedin city supply or water may be diverted to maintain existing irrigation commitments. There will also be some unavoidable net water loss to evaporation because of the low 0.6 metre annual rainfall at Onslow.

Discussion

The energy storage capacities indicated in Figure 2 are achieved at the expense of a large maximum water level range. The Onslow Reservoir at 800 metres was assumed to have an operating range of 80 metres, which would result in the two basins collectively having a between-level land surface exposure of approximately 60 km^2. This is a significant environmental impact, but complete 60 km^2 exposure would be infrequent.

One possibility would be to maintain the double-basin reservoir at a constant 800 metre elevation purely as a reserve against dry years. At all other times time this would give the appearance of a pair of natural lakes extending over 120 km^2 in combined area. It could be desirable in this case to excavate an open connection between the reservoirs to maximise recreational use. Constructing anchored floating islands and interlacing waterways on the new reservoir would go some way to compensate for the large seasonal water level fluctuations associated with dry years. However, care would be needed in selecting plant species to avoid problems of drifting weed at the pumped storage intake. Van Duzer (2004) gives a useful bibliography of floating islands in general.

Alternatively, the pumped storage scheme might operate on a continuous basis to reduce seasonal hydro lake fluctuations in the Clutha and Waitaki hydro-power schemes and provide active energy storage in support of wind energy developments. In fact, simulations indicate that an advantage to a continuous pumped storage mode is that it would reduce spillage losses from the Clutha and Waitaki hydro lakes if they were maintained at lower levels with reduced seasonal fluctuation, which also has an aesthetic advantage (Bear, 2005). With continuous operation the pumped storage reservoir would have a normal-year seasonal water level cycle over less than 10 metres. However, the insignificant natural inflow means that continuous operation would come at the cost of importing some power to avoid water levels trending down over the years due to pump-generation inefficiencies.

There would be major civil engineering involved in constructing any pumped storage scheme in the Onslow-Manorburn depression and an overview of the many aspects involved is beyond the scope of this paper. However, a few comments can be made with respect to some specifics to put the scheme in a global perspective.

To buffer against dry seasons the installed capacity of the pumped storage scheme would have to be reasonably large, say 1,500 MW in round figures. This is exceeded by installed capacity at a number of existing pumped storage schemes around the world (ASCE, 1996), including Ludington in the United States (2,000 MW) and Grand'Maison in France (1,800 MW). The tunnel length of 15-20 km is somewhat longer than other schemes, with the next longest being the seasonal Saurdal scheme in Norway (10.5 km). The Central Otago schist rock is not ideal for tunnel construction, but the Grand'Maison tunnel was built through medium-strength schists and sandstones. At maximum development to 800 metres the Onslow-Manorburn operating head would be 640-720 metres at Teviot or 580-670 metres at Lake Roxburgh, within the normal range for pumped storage schemes. The most distinctive feature of the Onslow-Manorburn scheme at maximum development would be its large energy storage capacity. By this measure it would be the world's largest pumped storage system, the next largest being the Saurdal scheme (7,760 GWh).

The Onslow-Manorburn emphasis on large-scale seasonal storage does not of course preclude investigations of smaller schemes elsewhere in the country to either provide temporary local power supply during outages or buffer transmission lines against peak loading. It could be interesting, for example, to evaluate the economics of an Auckland pumped storage scheme in both of these contexts.

Conclusion

The Onslow-Manorburn basin has the potential to more than triple the national hydro-power energy storage capacity by way of a large pumped storage reservoir linked to the Clutha River. The scheme might be held static as a dry year reserve or operated continuously on a seasonal basis. However, it is left an open question as to whether it would be viable within the current grid system in the absence of a complete analysis of economic, environmental, and engineering aspects. If it happened that the scheme is constructed to its maximum extent, then New Zealand's economic development could be aided by a very visible manifestation of a national power system well buffered against climatic fluctuations.

Acknowledgements

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References

American Society of Civil Engineers (ASCE) 1996: *Hydroelectric pumped storage technology international experience*. ASCE. New York. 378 p.

Bear, S. 2005: Hydrological evaluation of pumped storage in the Onslow-Manorburn basin. Master of Science thesis, University of Waikato, Hamilton, New Zealand. 140 p.

Van Duzer, C. 2004: *Floating islands: a global bibliography*. Cantor Press. Los Altos Hills, California. 400 p.

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