Meeting Date: 2 March 2022

Capacity and Energy Issues Associated with Low Hydro Storage and Inflows

Security and Reliability Council

The system operator has offered to present findings from scenarios they have developed to test the power system's ability to meet peak demand when hydro lakes are nearing their respective minimum operating levels. This paper sets out the scenarios and potential implications for capacity and energy and on rolling outages.

Note: This paper has been prepared for the purpose of an SRC discussion and eliciting SRC feedback. Content should not be interpreted as representing the views or policy of the Electricity Authority.

1. Power System Management

1.1.1 As part of its day-to-day management of the power system, the system operator is required to manage energy security and capacity. It runs various scenarios to achieve this, which in turn inform its policies and processes and help identify required changes.

1.1.2 This work is important, as highlighted by events such as 9 August 2021, particularly when peak demand occurs and there are constraints in parts of the system.

2. Purpose and approach

2.1.1 The aim of the system operator's paper (in Appendix A) is to present this information to the SRC, giving the opportunity for direct feedback on the approach, findings and outcomes, as part of the SRC's role to advise the Authority on issues of security and reliability of supply and system operator performance.

2.1.2 The paper sets out the following scenarios:

- Zero storage, low inflow – extreme winter daily demand profile
- Zero storage, low inflow – typical winter daily demand profile
- Capacity shortages outside of an emergency hydro scenario

2.1.3 For each scenario, the paper sets out the implications on capacity and energy and implications for rolling outages. The paper also sets out potential changes to approach and future analysis.

2.1.4 The paper notes that except for major infrastructure failure, the scenarios have a low probability but high impact. The main benefit from the scenarios is their use by the system operator in testing processes and policies.

3. Main conclusions

3.1.1 The following main conclusions are given in the paper:

- There is not a capacity issue at low hydro lake levels to provide the peak demand.
- Energy issues arise from being unable to sustain high levels of capacity when lake levels are at their minimum operating ranges. The resulting shortage would be approximately 5% of an average daily demand but could reach up to 18% if demand is high.
- Rolling outages may have limited effect overnight, as they could lead to reduced thermal generation rather than conserve hydro storage as, depending on the demand profile and need to maintain maximum capacity during peak periods, there could be little discretionary hydro being dispatched.
- Investments in the HVDC and the AC transmission network have enabled sufficient transmission capacity to (largely) make energy and capacity issues due to low hydro storage a national issue rather than an island-based issue. While upgrades to the Upper Clutha and Waitaki lines have reduced Southland import constraints, potential constraints at Benmore-Aviemore still exist on high HVDC transfer southwards.

- There is a potential gap in our current security of supply analysis where the information published by the electricity risk curves measures aggregated hydro storage at a national and South Island level, but that variation of storage levels across lakes may lead to generation capacity issues.

4. Questions for SRC

Q1. Does the SRC agree with the scenarios used and conclusions reached?

Q2. Does the SRC have any other suggestions about alternative scenarios?

Q3. Does the SRC have any comments on the changes the system operator proposes?

Q4. Does the SRC require further information at this stage?

Q5. What advice, if any, does the SRC wish to provide to the Authority at this stage?

Appendix A – system operator paper – Capacity and Energy Issues Associated with Low Hydro Inflows and Storage

Capacity and Energy Issues Associated with Low Hydro Storage and Inflows

A paper for the Security and Reliability Council

Date: 9 February 2022

Capacity and Energy Issues Associated with Low Hydro Storage and Inflows

Summary

This paper looks at the power system's ability to meet peak demand given physical and legal constraints that may exist when the hydro lakes are at or nearing their respective minimum operating limits. This analysis has been used to test the robustness of our current policy and process within the security of supply framework[1] and has identified some required changes. These changes are regarding the use of rolling outages overnight in a hydro shortage situation and increased monitoring in the event of a large hydro lake storage imbalance.

Physical constraints relate to operational issues such as low hydraulic head at low lakes, HVDC transfer limits, and AC system constraints. Legal constraints are largely associated with the resource consents that exist for the hydro schemes such as required lake levels or minimum flows.

For this analysis we have produced three scenarios that have been analysed over the period of a day. The first two scenarios explore situations when storage is exhausted and inflows are low, and the third when storage is concentrated at one hydro scheme.

Our conclusions from this analysis are that only in rare circumstances would capacity issues from low hydro storage arise before energy issues. These energy shortages would be signalled to the market by the current security of supply framework, which we plan to enhance in order to further capture the circumstances identified in this paper.

Common themes from engagement with generators

To identify the physical and legal constraints that exist at each lake as it approaches then reaches the minimum operating level, we spoke with the five operators of New Zealand's major hydro schemes[2]. Some common themes were reported:

- Across the hydro schemes concerned, it was reported that ramp rates would not be an issue in reaching maximum capacity or providing reserves.
- When presented with the low storage, low inflow scenario many of the generators explained that they would be capable of reaching peak output for a high demand interval once, but then a significant amount of time would be required to recharge the dams in order to repeat this. Therefore, the main issue would be having sufficient energy inflows in order to meet peak demand and sustain output over several consecutive days with high periods of demand. For this reason, we undertook analysis to cover a whole day rather than a single peak within a day.
- Operating lakes at low levels leads to a drop in head pressure at the station. In some places this leads to a drop in maximum capacity, but in all schemes, it leads to lower efficiency, meaning that more metres cubed of water need to be used per MWh of energy generated. This would likely be reflected in higher-priced generation offers at low lake levels.
- For the stations that form a chain along a river, balancing and timing of water flows between head ponds and stations would become critical but was mostly reported as manageable.

Scenario analysis

Three scenarios were analysed to explore implications for energy and capacity, as well as to test the robustness of the current rolling outages policy. These scenarios are based on the present-day demand and generation mix and therefore are an analysis of the current state of the electricity system[3]. These scenarios were:

1. Zero storage, low inflow – extreme winter daily demand profile
2. Zero storage, low inflow – typical winter daily demand profile
3. Capacity shortages outside of an emergency hydro scenario

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[1] https://www.ea.govt.nz/operations/wholesale/security-of-supply/security-of-supply-policy-framework/

[2] Contact, Genesis, Meridian and Trustpower. Mercury provided their response via email. All confidential information has been aggregated. All participants willingly participated.

[3] In Appendix 3 we have provided a scenario covering 2023 with the major generation changes signalled to occur

Scenario 1: Zero storage, low inflow – extreme daily demand profile

We have defined this scenario as a winter shortage scenario where:

- daily demand is at the 95th percentile
- controlled and contingent hydro storage is assumed to be exhausted
- hydro inflows are at the bottom 5th percentile level

This a worst-case hydro storage scenario and is what the security of supply policies and market design incentivise the market to avoid.

Figure 1**Error! Reference source not found.** shows the demand and generation scenario. The non-hydro generation sources are placed at the bottom of the stack, followed by must-run hydro and controllable hydro (running with 5th percentile inflows) at the top.

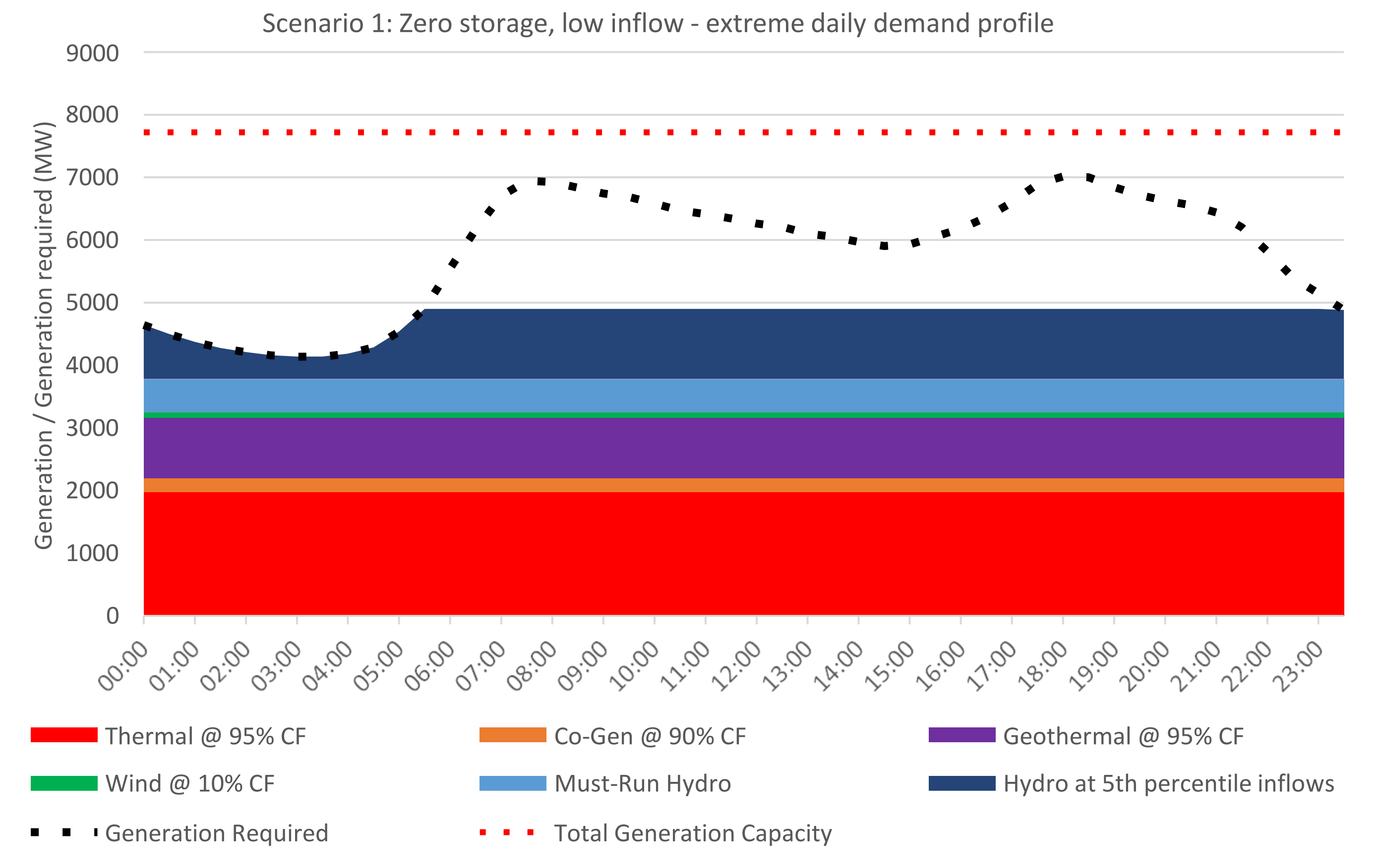

Figure 1: Scenario 1 – energy shortage

Implications on capacity and energy

In Figure 1, the unfilled area of generation shows that a significant amount of both energy and capacity are required from controllable hydro generation in order to meet demand. However, the total generation capacity figure, which factors in operation issues observed at minimum operational ranges, shows that meeting a single instantaneous peak would be achievable (unless a significant amount of plant was on outage).

However, generation could not meet demand over the day modelled. The energy shortfall when daily demand is in the 95th percentile is 26 GWh which against the required generation of 140 GWh, represents an 18% energy shortfall.

Implications for Rolling Outages

In this scenario with available hydro storage at 0 GWh, New Zealand would be in an Emergency OCC situation (official conservation campaign) and rolling outage modelling would have already been initiated by the System Operator[4], with rolling outages having been signalled to the market.

[4] Rolling outage modelling is commenced at the 10% Emergency Risk Curve.

This scenario indicates rolling outages in the worst case (no hydro storage left) could reach up to 18% of daily demand. As the HVDC is limited to 750 MW southward capacity[5], the modelling indicates that the South Island may require a higher proportion of rolling outages than the North Island in a high demand scenario (since more generation would be available in the North Island than the South Island in this scenario). The energy shortfall was calculated as 28% for the South Island.

In addition, with low generation in the lower South Island, particularly the lower Waitaki generation, power transfer on Aviemore-Benmore 220 kV circuits needs to be limited into the lower South Island to avoid post-contingent[6] overloading. This can be achieved by lifting generation in the lower South Island or by reducing southward flow on the HVDC. Part D of the System Security Forecast (SSF)[7] states that generation in the region might need to be increased to 807 MW in the winter in order to fully utilise the full southward capacity of the HVDC while avoiding the Aviemore-Benmore constraint. However, in our 5th percentile inflow scenario, total generation from Manapouri, Clutha and Waitaki is estimated at ~575 MW maximum, indicating that managing the Aviemore-Benmore constraint under these circumstances would be require limiting southward HVDC transfer, further increasing the shortfall in the South Island.

Since capacity is not the key issue, rolling outages would be shaped to avoid shortages during high impact periods. Figure 2 below demonstrates that while shaping generation can target peak period running, the size of energy shortfall does not change. It also shows there is limited potential to conserve energy overnight as it will quickly constrain off non-controllable hydro generation, most likely thermal generation.

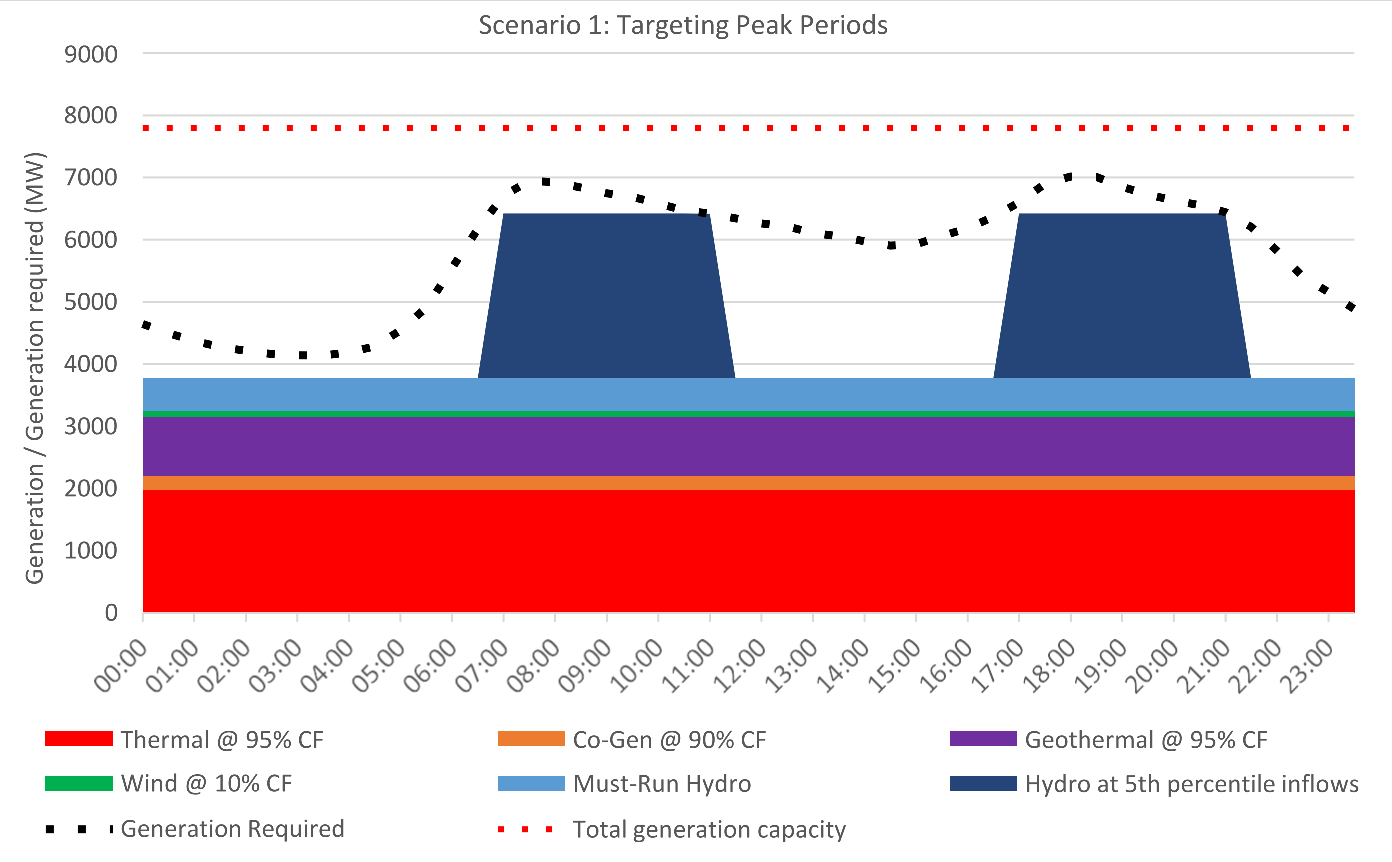

Figure 2: Scenario 1 – rolling outages

Scenario 2: Zero storage, low inflow – average winter daily demand profile

This scenario uses the same inputs as Scenario 1 with the exception of an average winter daily demand profile rather than an extreme daily demand profile:

- demand is set as the average over August 2021

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[5] The HVDC has a maximum rating of 815MW AC received at Benmore, this has been reduced to 750MW for this analysis to account for reserves required, particularly for the South Island ECE risk.

[6] A contingency is defined as the unplanned tripping of a generator or a circuit

[7] https://www.transpower.co.nz/sites/default/files/bulk-upload/documents/Part%20D%20SI%20Backbone.pdf

- controlled and contingent hydro storage is assumed to be exhausted
- hydro inflows are at the bottom 5th percentile level

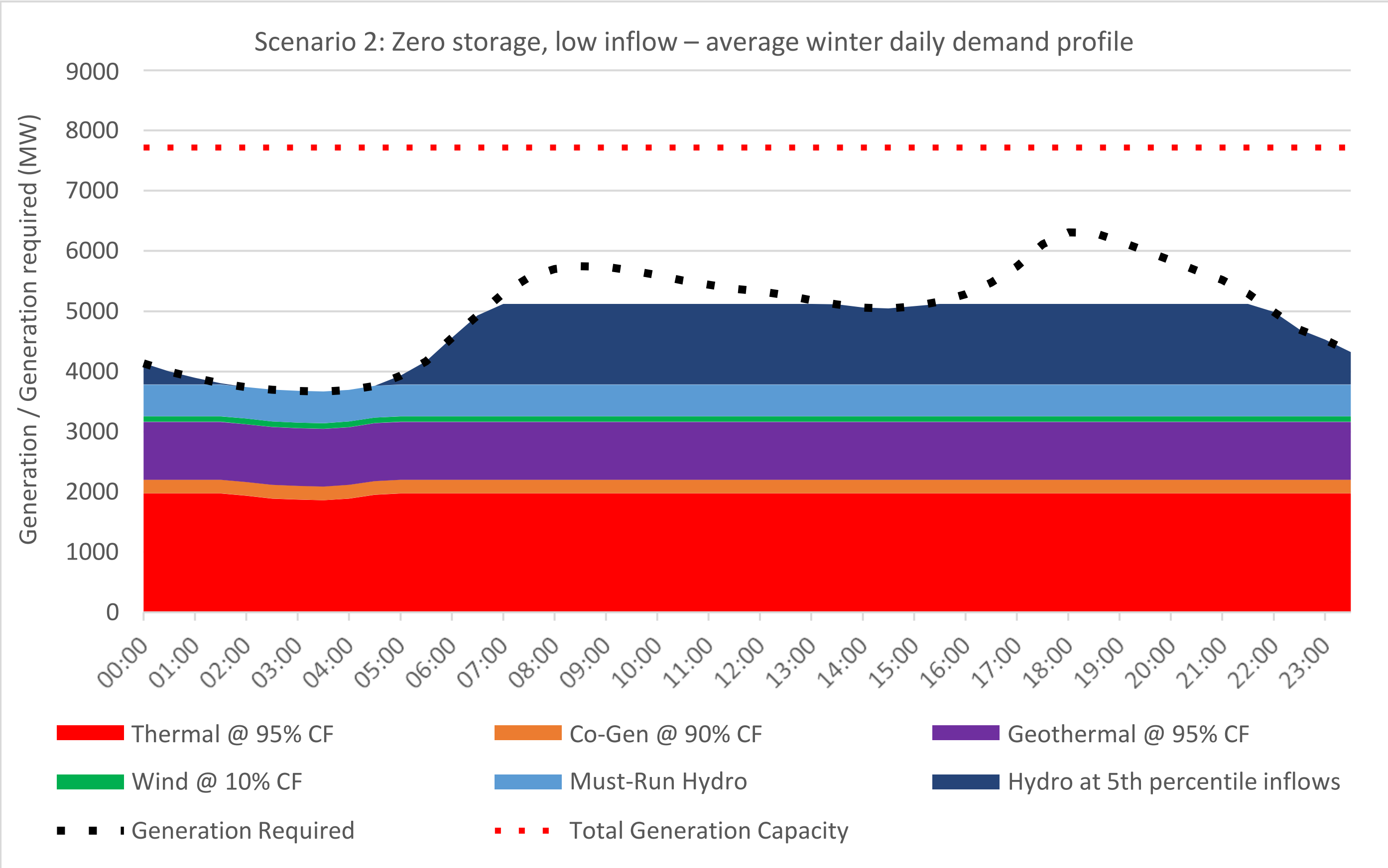


Figure 3: Scenario 2 - energy shortage

Implications on Capacity and Energy

Figure 3 shows meeting any instantaneous peak demand in scenario 2 is achievable as the total generation capacity is above the generation required. The total energy shortfall is 6 GWh over the day or 5% of demand.

Implications for Rolling Outages

As in Scenario 1 with available hydro storage at 0 GWh, New Zealand would be in an Emergency OCC situation and rolling outage modelling would have been initiated by the System Operator. It is likely planned rolling outages would have been signalled to the market.

The Aviemore-Benmore constraints described in scenario 1 also apply in this scenario, and there is potential that greater proportional of load shedding will be needed in the South Island if sufficient energy is not available at the Southland generation stations to enable high HVDC southward flow.

Figure 3 also shows on a typical winter's night there is no, or very limited, potential to conserve energy overnight as it will quickly constrain off non-controllable hydro generation such as thermal generation rather than allow conservation of controlled hydro storage.

Scenario 3: Capacity Shortages Outside of an Emergency Hydro Scenario

This scenario was designed to explore the possibility of a capacity or energy shortage arising due to low or zero hydro storage across several hydro schemes, while total national storage was above the 10% risk curve (ie. before a conservation campaign, customer compensation scheme or rolling outages had been initiated).

The scenario assumes Lake Pukaki, our largest hydro storage lake with 39% of total national storage capacity, has a moderate amount of remaining storage, and for all other lakes to be at their minimums.

Scenario 3 key assumptions are:

- demand is at the 95th percentile
- Lake Pukaki has sufficient storage (~50% full for the purpose of this analysis)

- all other controlled and contingent hydro storage is assumed to be exhausted
- hydro inflows are at the bottom 5th percentile level

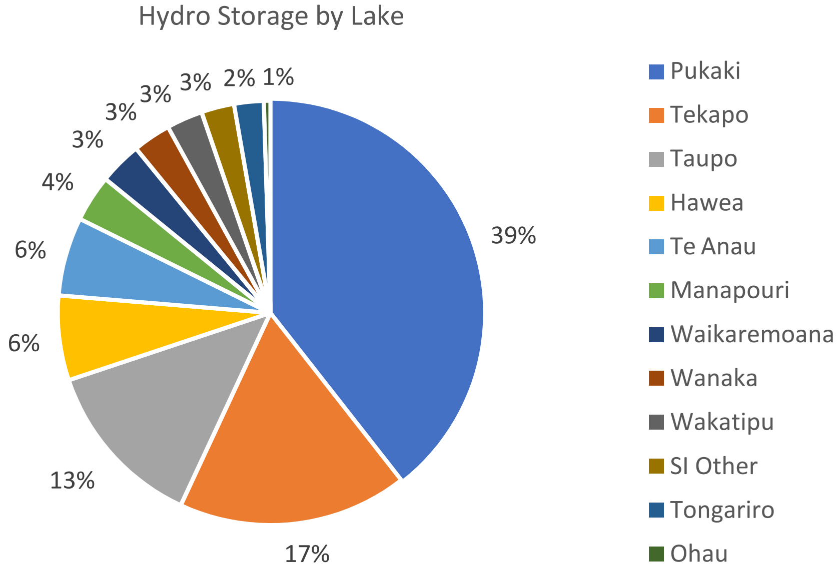


Figure 4: Size of Lake Pukaki in comparison with other hydro lakes

The electricity risk curves for scenario 3 are shown below in Figure 5. They show a hypothetical year where national hydro storage falls to 1,000 GWh in August, with all storage at Lake Pukaki (at ~50% full). National hydro storage at this point is 550 GWh above the 1% risk curve and 739 GWh above the 10% risk curve.

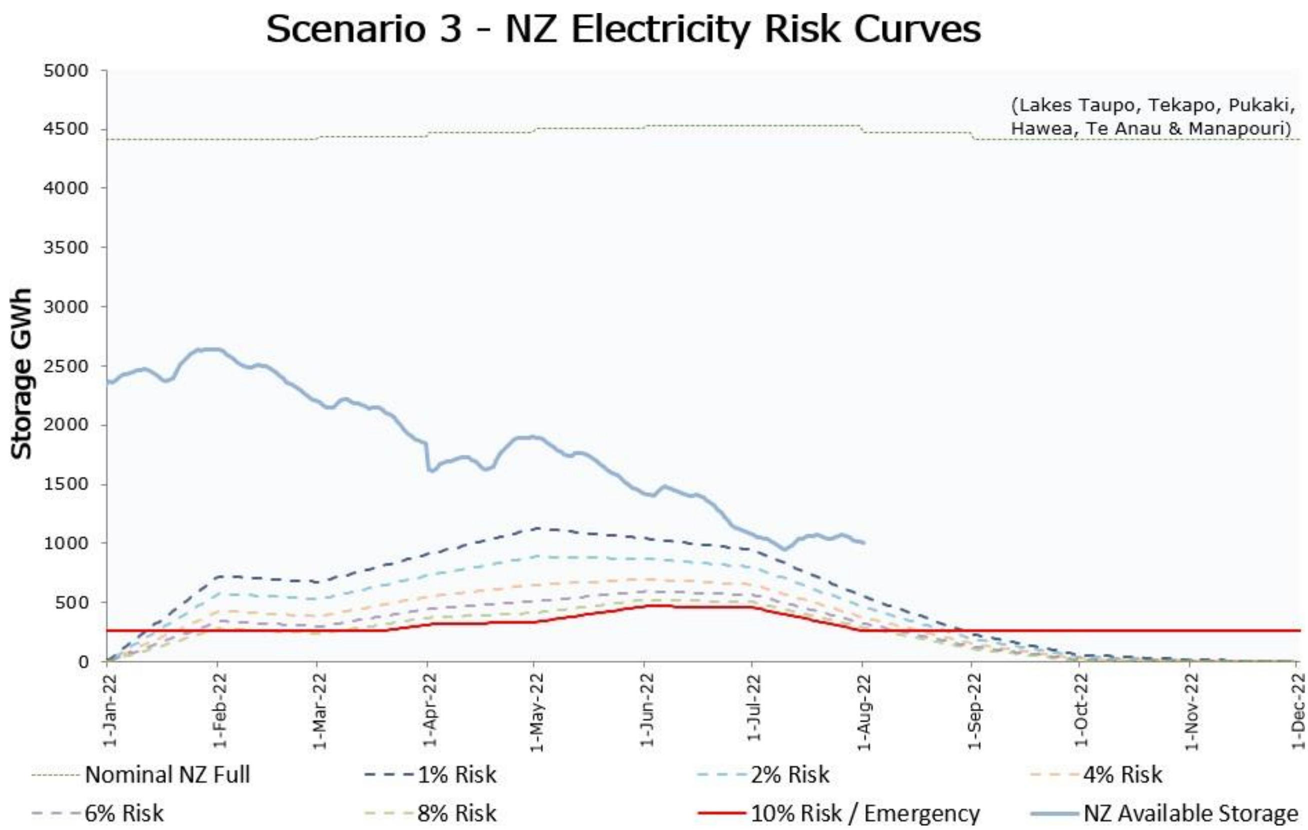


Figure 5: NZ ERCs showing storage at 1,000GWh but clear of the risk curves

Scenario 3 has the Waitaki stations, which are fed by Lake Pukaki, generating at full output, and the other hydro schemes generating within the 5th percentile inflows available to them.

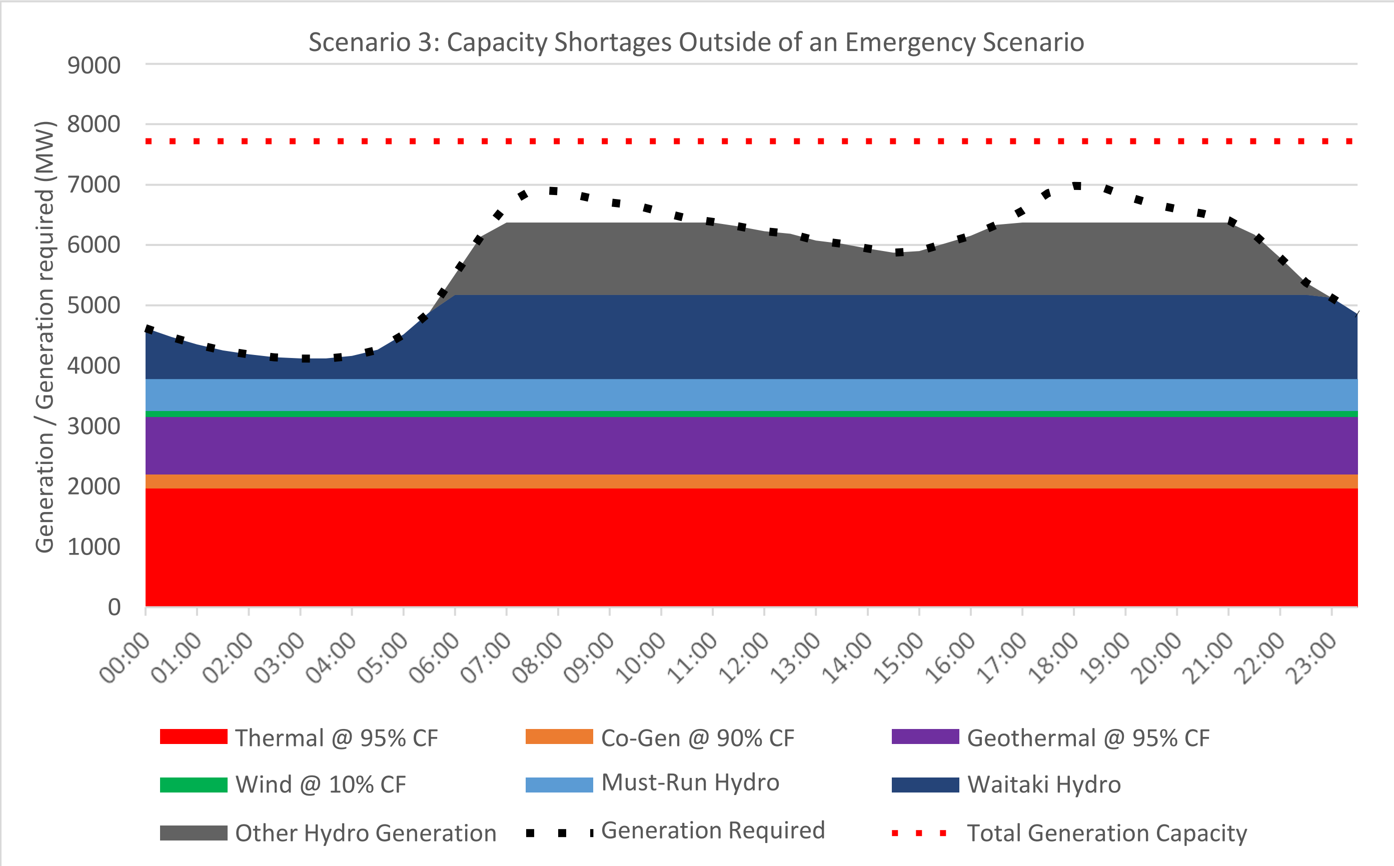


Figure 6: Scenario 3 – energy shortages

Implications on Capacity and Energy

Figure 6**Error! Reference source not found.** shows an energy shortfall of 3 GWh given a 95th percentile daily demand profile; this shortfall would be 2% of a 95th percentile winter daily demand profile. This shows that it is possible for a shortage situation to arise before the 10% risk curve has been breached and preparations for a shortage situation have been made. However, the corresponding capacity shortfall is large at ~650 MW. To avoid unplanned rolling outages a small amount of storage would need to be available at either the Clutha, Manapouri or Waikato schemes as these have greater than 650 MW of capacity. Appendix 3 shows this scenario with likely changes to generation for 2023.

Implications for Rolling Outages

Our rolling outage policy states if we think there is a 50% chance or more that rolling outages will be required the System Operator can instruct them. Our current process is designed to provide up to 21 days warning and starts monitoring from the 10% risk curve. Using existing security of supply policies and processes, the situation shown in scenario 3 would see the requirement for rolling outages for supply shortages potentially only becoming apparent in the market schedules with one to seven days' notice. This would limit the time available to advise the market who can act by reducing load, shifting load, conserving hydro when possible ahead of time.

As the detailed modelling behind the simulated storage trajectories would forecast load shedding in this scenario, we have adjusted our process to monitor for forecasted load shedding and to begin our detailed rolling outage modelling if this is seen.

In this scenario there would be additional energy available overnight from Lake Pukaki, therefore shifting controllable load from peak to off-peak; this could also be an additional mitigation option.

Conclusion

With the exception of major infrastructure failure, all these scenarios have a very low probability but high impact. They test the boundaries of possible security of supply challenges, which helps to test our policies and processes.

This analysis has shown that:

1. There is not a capacity issue at low hydro lake levels.
2. Energy issues arise from being unable to sustain high levels of capacity when lake levels are at their minimum operating ranges. The resulting shortage would be approximately 5% of an average daily demand but could reach up to 18% if demand is high.
3. Rolling outages have limited effect overnight, as they will likely lead to reduced thermal generation rather than conserve hydro storage.
4. Investments in the HVDC and the AC transmission network have enabled sufficient transmission capacity to (largely) make energy and capacity issues due to low hydro storage a national issue rather than an island-based issue. While upgrades to the Upper Clutha and Waitaki lines have reduced Southland import constraints, potential constraints at Benmore-Aviemore still exist on high HVDC transfer southwards.
5. There is a potential gap in our current security of supply analysis where the information published by the electricity risk curves measures aggregated hydro storage at a national and South Island level, but that variation of storage levels across lakes may lead to generation capacity issues.

We will use the findings of this analysis to:

1. Update our rolling outage processes and policies so that distribution companies are aware that rolling outages are unlikely to happen during night-time trading periods with low demand.
2. Adjust our simulated storage trajectory process to monitor for forecast load shedding and we may begin our detailed rolling outage modelling if this is occurring. This trigger for this process will be if a large imbalance in hydro storage is observed across the lakes, e.g. as in scenario 3 described above.

Appendices

Appendix 1: Approach to analysis

Consistent with the terminology used in the Security of Supply Annual Assessment (SoSAA), this paper refers to capacity as the ability to meet an instantaneous peak (MW) and energy to mean generation or demand over a time period (MWh). Energy and capacity are closely linked, and as lake levels are approaching their minimums, the energy constraints on capacity become more significant.

To identify the physical and legal constraints that exist at each lake as it approaches then reaches the minimum operating level, we spoke with the five operators of New Zealand's major hydro schemes[8]. We have then assumed the following environmental factors to reflect those of an emergency situation associated with low lake levels:

- All controllable thermal (including three Rankine units) are running at maximum capacity.
- Daily inflows in the bottom 5% for each hydro catchment.
- Winter daily demand profile.
- HVAC and HVDC constraints as outlined in the System Security Forecast (SSF).
- Reserves are not constraining the HVDC[9] and the HVDC is able to send 750 MW[10] southwards.
- A small allowance for generation outages, planned or unplanned; using a similar assumption to that used in the Electricity Risk Curves where we would expect all deferrable outages to be deferred.
- Must-run and run of river hydro has been estimated from a 5th percentile inflow sequence to uncontrolled schemes as well as the provided minimum flow rates through the controllable hydro schemes.
- Wind generation has been set as 10% of installed capacity to account for the lower end of its variability.
- Generation required is demand plus 3.5% transmission losses.
- We have assumed Tiwai is operating three pot lines (a total of 572 MW).

We have then applied a supply-demand balance model similar to that use in the New Zealand Generation Balance (NZGB) calculations to create worst case scenarios that test for capacity issues.

Appendix 2: Modelling Inputs

Item	Values Used
Demand	95th Percentile August 2021 Demand / Average August 2021 Demand
Generation required	Demand plus 3% (losses)
Hydrological Inflows	5th Percentile August (1926 – 2021)
Thermal Capacity	2,077 MW at 95% capacity factor = 1,973 MW
Co-gen Capacity	253 MW at 90% capacity factor = 228 MW
Geothermal Capacity	1,010 MW at 95% capacity factor = 960 MW
Wind Capacity	914 MW at 10% capacity factor = 91 MW
Hydro Capacity	5,228 MW at 90% capacity factor = 4,705 MW
Must-Run Hydro	527 MW

[8] Contact, Genesis, Meridian and Trustpower. Mercury provided their response via email. All confidential information has been aggregated. All participants willingly participated.

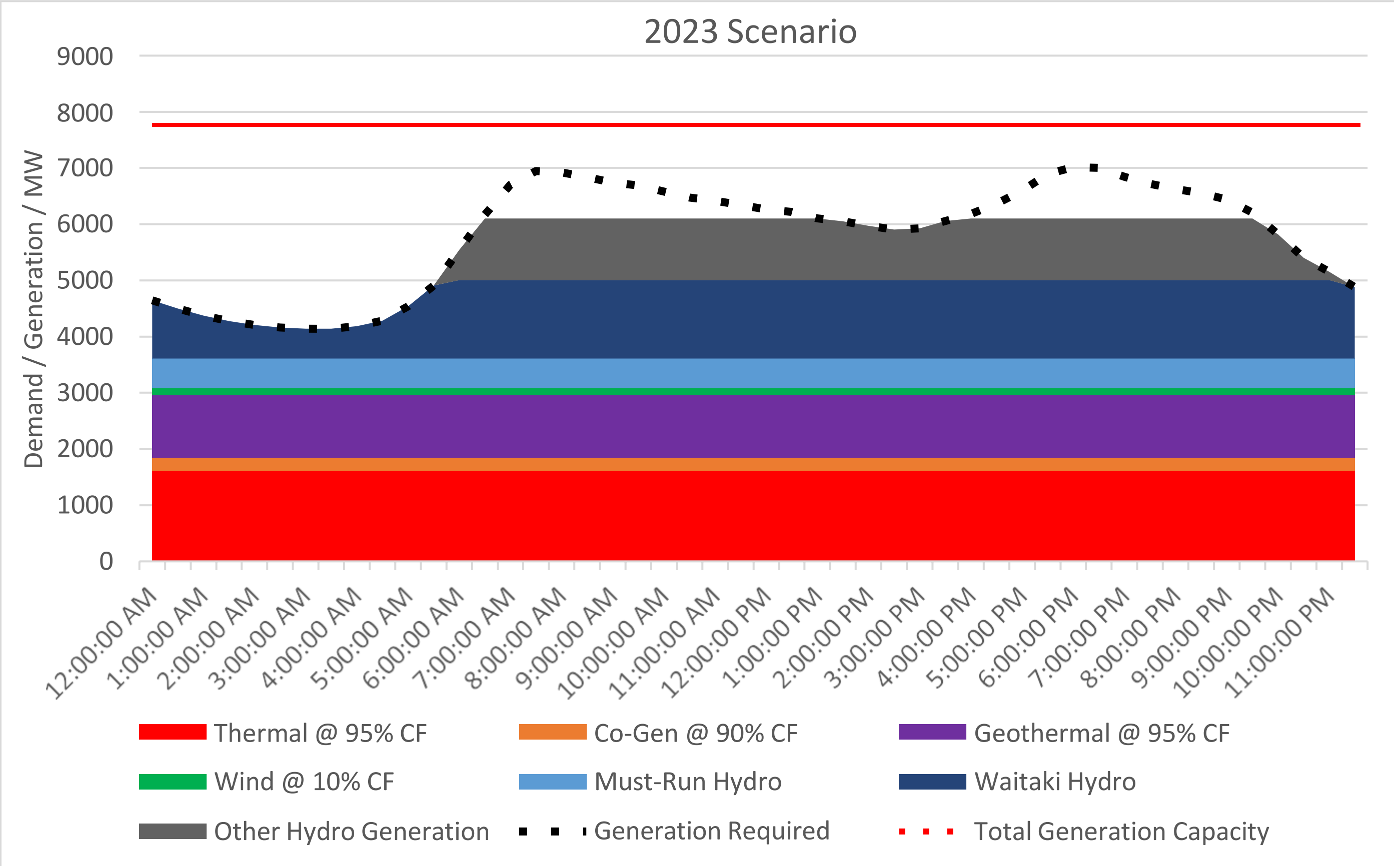
[9] During periods of low lake levels there are high levels of South Island reserves. Post the 2013 HVDC upgrades it is expected that South Island reserve would not be the limit South Transfer. It should also be noted that Tiwai could provide additional reserves if needed.

[10] Given a risk subtractor of 615 MW this requires 135 MW of South Island reserve for a CE event. For a DC ECE event it is assumed the Tiwai Point Smelter would offer Interruptible Load. This combined with previously observed levels of South Island generation reserve and the amount of AUFLS's would sustain this level of HVDC transfer South.

Appendix 3: 2023 scenario - TCC decommission / Tauhara B commissioned / Turitea South & Harapaki commissioned

This scenario has been included to capture the major generation changes signalled to occur before winter 2023. That is, the decommissioning of the 377 MW Taranaki Combined Cycle thermal plant, and the commissioning of the 168 MW Tauhara B geothermal plant and the 103 MW and 176 MW wind farms at Turitea South and Harapaki.

In this scenario the shortfall increases to 6.1 GWh / 900 MW



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