Hydrological Modelling Dataset

Report 3: Storage and Spill Series Descriptions

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Preface

A large proportion of New Zealand's electricity needs are met by generation from hydro power. Information about the distribution of inflows and the capability of the various hydro systems is necessary to ensure a reliable, competitive and efficient market and electricity system.

The hydrological modelling dataset (HMD) is a dataset of hydrological information made available by the Electricity Authority. The dataset was known as the SPECTRA update until 2010. In 2015 the dataset was revised to become the HMD, a comprehensive dataset that can be relied upon by modellers and analysts to test scenarios, provide commentary and inform decisions.

The HMD is comprised of data provided by hydro generators and supplemented with some from other sources. These parties are acknowledged for their contribution and for making this data available.

The HMD consists of three main components:

1. Infrastructure and hydrological constraint attributes:

   This dataset records standing information about the capability of the main hydro schemes.

2. Flows:

   This time series dataset records data for inflows for reservoirs and flows at various existing or potential hydro generating sites.

3. Storage and spill:

   This time series dataset records storage for the main hydro schemes.

This report describes the third component of the HMD, the storage and spill series.

Contents

1. Introduction

This Hydrological Modelling Dataset (HMD) full update was requested by the Electricity Authority and includes data to 31 December 2017.

A full update recalculates all data back to 1932 rather than an interim update that simply adds one year of data to the end of the previous full HMD update. This full update recalculates data from 1 January 1932 to 31 December 2017.

The HMD consists of six datasets:

- Infrastructure attributes:

  Lists the changes over time to the 'plant factors' or 'average efficiency factors' for each of the power stations associated with the 10 largest reservoirs.

- Hydrological constraints:

  Lists the constraints put on hydrological parts of schemes usually via consent conditions. This was completed for the power stations associated with the 10 largest reservoirs in New Zealand.

- Actual flows:

  a. 'Actual' inflows or outflows to or from a number of reservoirs in New Zealand. The inflows are modelled data, the outflows are generally measured data;
  b. Tributary flows or local inflows into various reservoirs;
  c. Hypothetical 'actual' flows, i.e., flows which could occur under certain regimes; and
  d. Actual river flows at gauging stations which could be possible hydro-power schemes in the future; and
  e. Average daily outflows from daily derived flow records.

  Many of these are also part of the natural flow dataset.

- Natural flows:

  a. 'Natural' uncontrolled inflows to a number of reservoirs in New Zealand;
  b. Modelled natural inflows or tributary inflows to reservoirs, as though they are uncontrolled; and
  c. River flows at gauging stations which could be possible hydro-power schemes in the future.

  Many of these are also part of the actual flow dataset.

- Lake storage:

  Daily active storage volumes from 1980 to 2016 for the 10 largest hydro lakes in NZ

- Spill volume:

  Weekly spill flow data for 25 sites in New Zealand including the 10 largest hydro-lakes and each of the structures downstream.

  The spill data are for weeks from Monday to Sunday and are recorded at 24:00 on the last day of the week. The first weekly spill data for sites starting in 1980 begins on 31 December 1979 at 00:00 and runs to 6 January 1980 at 24:00.

The lake storage, spill volumes, infrastructure attributes, and hydrological attributes datasets were produced for the first time in 2015.

The average outflows of the reservoirs that are a part of the Waikato and Waitaki schemes were produced for the first time in 2017.

Flow routines for actual and natural flows are re-run for each update and new datasets created. These datasets are then compared with previous data to ensure continuity and accuracy. Explanations of any differences between successive full update datasets are provided in a separate report – "Hydrological Modelling Dataset: HMD Flow Series Comparison".

The following Power Companies have provided data for this update:

- Contact Energy Ltd
- Genesis Energy Ltd
- Meridian Energy Ltd
- Mighty River Power Ltd

All input data records have been checked for gaps and, where necessary, these have been filled to provide continuous time series.

1.1. Climate Change

The HMD is based on recorded flows, and the interaction of these flows with both HEP infrastructure and the consenting framework. No specific consideration is given to the future potential effects of climate change on the flow regimes of the various rivers.

The raw data, however, contain all the inherent climatic effects on the recorded flow regimes of the various rivers. Consequently, the data include seasonality, persistence, and any climatic trends or cycles which have affect the flow regimes.

Where data have been synthesised, to fill gaps in the records, this is based on correlation with the most appropriate ‘donor’ site, over the longest period of concurrent data. Consequently, the synthetic records include any effects of climatic variability inherent in the ‘donor’ record. Since the flow regimes fo the two records have similar characteristics, hence their correlation, the transference of any climate signature is appropriate. However, since the longest period of concurrent record is used to derive the synthetic series, the correlation will include the average effect of any climatic variability of change over that time. Shorter-term climatic effects will not be apparent in the synthetic data. Such an approach is the best possible to synthesise periods of missing record, and results in the least error while still including any longer-term climate signature.

It should be noted, that the use of daily average flows in the HMD provides significant smoothing of any minor effects of climate variability and change, especially the potential impact of short duration – high intensity flood events.

The HMD therefore contains all those actual longer-term climatic signatures which have affected the various rainfall-runoff relationships. Any shorter or more subtle trends are smoothed over periods of synthetic flow data. HMD does not provide any quantitative consideration of the potential effects of climate change in the future.

1.2. The Power Archive

A significant amount of input data for the HMD series are from the Power Archive. In the mid-late 1970s the Power Division of the Ministry of Works and Development commenced development of the ‘Power Archive’, a repository for all hydrometric data relating to the various hydro systems, reservoirs and dams throughout New Zealand. Over time the ‘Power Archive’ evolved to include not only the hydrometric data but also various additional outputs such as machine flows, generation, spills, inflows, gate openings, and natural inflows and lake levels.

Management of the ‘Power Archive’ has also moved over time from the Ministry of Works and Development, to the Works and Development Services Corporation NZ, to Works Consultancy Services, and currently Opus International Consultants Ltd (Opus).

With the break-up of the Electricity Corporation of New Zealand into a number of separate companies the ‘Power Archive’ was also partitioned. While the majority of the original ‘Power Archive’ is still maintained by Opus a number of the power companies have taken these services in-house, e.g., Trustpower and most recently Genesis Energy. Ongoing maintenance of the ‘Power Archive’ by Opus has ensured continuity and consistency of independently quality assured data for use in analysis and modelling.

Despite this partitioning of the ‘Power Archive’ the various hydrometric and generation set are still generally collectively referred to as the ‘Power Archive’.

1.3. Quality codes

The National Environmental Monitoring Standards steering group (NEMS) has prepared a series of environmental monitoring standards on authority from the Regional Chief Executive Officers (RCEO) and the Ministry for the Environment (MFE) (NEMS, 2013).

These standards describe how to collect, process, retain and archive environmental data, using best practice methodologies. The NEMS incorporates a common National Quality Code Schema (NQCS) across all measured environmental parameters, which assigns a final Quality Code to the data. This code describes how the data meets the various requirements required under each environmental standard; the degree of rigour in which the standard is applied affects the final quality of the data.

It was recommended that these standards were adopted throughout New Zealand and all data be collected, processed and quality coded appropriately.

The National Quality Code Schema is divided into six ‘Zones of Quality’ within a numeric index which describes how the collected and processed environmental data meets the relevant standard. These six zones have a parent code summarising the overarching quality of the data; 100 represents Missing Record; 200 is Unverified or Cautionary Data; 300 is Synthetic; 400 is Poor Quality; 500 is Fair Quality; and 600 is Good Quality. To achieve ‘Good Quality’ data requires each component of the standard to be practised; from the data collection stage to archiving.

The NQCS can be introduced in its basic parent form or it can be expanded upon to provide more data quality detail by agencies where a greater level of detail is required; detail relating to data quality and operational requirements and standards. This expansion to the NQCS is called ‘child coding’. These ‘child codes’ are currently allocated in-house, and have therefore been developed to differentiate between data quality in the HMD.

Table 1.1 shows the quality codes used for the HMD. In the event that no measured data was recorded and replacement data could not be reasonably calculated, a Missing Record is filed with a quality code of ‘100’ assigned to the null time period. The direct measurement of flow and the spill flow volumes were both coded as ‘200’, because the quality of this data is non-verified. This number is a ‘parent code’ and has been outlined by the NQCS. All of the rest of the quality codes used for the HMD are ‘child codes’ that were created under the ‘parent code’ of synthetic data (300). A ‘301’ code denotes that the data was created via simple arithmetic, for example, Site 1 + Site 2. The ‘310’ code is used when data is made via a correlation with another dataset, for example, when there is no available data for a site so a relationship is established with an adjacent station to correlate the data. The codes ‘320’ and ‘325’ represent data that has been manufactured, usually with calculations or models. The ‘330’ code denotes that the data has been entered as the median flow, for example, for gap filling where other methods were not deemed appropriate. The ‘335’ describes data used to fill small gaps using a combination of correlation, visual interpolation and site specific information from the recording authority to provide the most likely flow. The ‘340’ code is used when the data has been ‘replicated’ for larger periods of data. This may occur when whole or parts of years were replicated and entered to fill a piece of missing record, using a combination of correlation, calculation and modelling. This occurred often between 1931 and 1934 when there were a limited number of sites operating at this time. The last code is ‘350’ where the data is synthetic but is of an unknown origin.

Table 1.1 Description of the quality codes used for the HMD

CODE	DESCRIPTION
100	Missing Record
200	Unknown or non-verified quality
301	Simple arithmetic
310	Correlation
320	Manufactured via calculations or models (WSP Opus)
325	Manufactured by the recording authority
330	Median flow
335	Small gap filling via correlation, calculation and interpolation
340	Replicated data
350	Unknown origin

1.4. Dataset summary

1.4.1. Data Sources

The HMD data record for any the flow series are often a composite record derived using different methods for different periods, however for the storage and spill series, the records have been derived using a single method in each case. Table 1.2 and Table 1.3 lists the source of the record for each series and period for the storage and spill datasets, respectively. The quality code for record is listed along with the definition of the quality code in Table 1.1.

Table 1.2: Quality of HMD Storage series - North and South Island

DATASET	PERIOD	QUALITY CODE	CODE DEFINITION
Lake Taupo Storage	01/01/80 - 31/12/17	320	Synthetic – Manufactured (Opus)
Lake Waikaremoana Storage	01/01/80 - 31/12/17	320	Synthetic – Manufactured (Opus)
Lake Ohau Storage	01/01/80 - 31/12/17	320	Synthetic – Manufactured (Opus)
Lake Tekapo Storage	01/01/80 - 31/12/17	320	Synthetic – Manufactured (Opus)
Lake Pukaki Storage	01/01/80 - 31/12/17	320	Synthetic – Manufactured (Opus)
Lake Wanaka Storage	01/01/80 - 31/12/17	320	Synthetic – Manufactured (Opus)
Lake Hawea Storage	01/01/80 - 31/12/17	320	Synthetic – Manufactured (Opus)
Lake Wakatipu Storage	01/01/80 - 31/12/17	320	Synthetic – Manufactured (Opus)
Lake Te Anau Storage	01/01/80 - 31/12/17	320	Synthetic – Manufactured (Opus)
Lake Manapouri Storage	01/01/80 - 31/12/17	320	Synthetic – Manufactured (Opus)

The spill data are calculated for weeks from Monday to Sunday and are recorded at 24:00 on the last day of the week. Therefore, the first weekly spill data for sites starting in 1980 begins on 31 December 1979 at 00:00 and runs to 6 January 1980 at 24:00.

Table 1.3: Quality of HMD Spill series - North and South Island

LAKE	DATASET	PERIOD	QUALITY CODE	CODE DEFINITION
Lake Waikaremoana	Onepoto	02/11/98 - 31/12/17	200	Non verified data
	Waikareteheke River at Piripaua	22/04/02 - 31/12/17	200	Non verified data
	Waikareteheke River at Upstream Mangaone	30/06/97 - 31/12/17	200	Non verified data
Lake Tekapo	Lake Tekapo at Gate 17	31/12/79 - 31/12/17	200	Non verified data
	Lake George Scott to Tekapo River	31/12/79 - 31/12/17	200	Non verified data
Lake Pukaki	Lake Pukaki	31/12/79 - 31/12/17	200	Non verified data
Lake Ruataniwha	Lake Ruataniwha	08/12/86 - 31/12/17	200	Non verified data
Lake Ohau	Lake Ohau	31/12/79 - 31/12/17	200	Non verified data
Lake Benmore	Lake Benmore	31/12/79 - 31/12/17	200	Non verified data
Lake Aviemore	Lake Aviemore	31/12/79 - 31/12/17	200	Non verified data
Lake Waitaki	Lake Waitaki	31/12/79 - 31/12/17	200	Non verified data
Lake Te Anau	Lake Te Anau	31/12/79 - 31/12/17	200	Non verified data
Lake Manapouri	Lake Manapouri	31/12/79 - 31/12/17	200	Non verified data
Lake Hawea	Lake Hawea	31/12/79 - 31/12/17	200	Non verified data
Lake Dunstan	Clyde Dam	20/04/92 - 31/12/17	200	Non verified data
Lake Roxburgh	Lake Roxburgh	31/12/79 - 31/12/17	200	Non verified data
Lake Taupo	Lake Taupo	31/12/79 - 31/12/17	200	Non verified data
Lake Aratiatia	Lake Aratiatia	31/12/79 - 31/12/17	200	Non verified data
Lake Ohakuri	Lake Ohakuri	31/12/79 - 31/12/17	200	Non verified data
Lake Atiamuri	Lake Atiamuri	31/12/79 - 31/12/17	200	Non verified data
Lake Whakamaru	Lake Whakamaru	31/12/79 - 31/12/17	200	Non verified data
Lake Maraetai	Lake Maraetai	31/12/79 - 31/12/17	200	Non verified data
Lake Waipapa	Lake Waipapa	31/12/79 - 31/12/17	200	Non verified data

LAKE	DATASET	PERIOD	QUALITY CODE	CODE DEFINITION
Lake Arapuni	Lake Arapuni	31/12/79 - 31/12/17	200	Non verified data
Lake Karapiro	Lake Karapiro	31/12/79 - 31/12/17	200	Non verified data

2. Lake Storage

In February 2009 WSP Opus produced (for the Electricity Commission) a chronology and history of the 10 major lakes used for hydro generation in New Zealand (Knight & McConchie, 2009). These lakes included: Taupo and Waikaremoana in the North Island; and Ohau, Tekapo, Pukaki, Wanaka, Hawea, Wakatipu, Te Anau and Manapouri in the South Island. That report discussed the changes in water level over time, and provided an explanation for the significant changes caused by alterations to control structures and consent conditions. All the water levels were, however, presented relative to the local level datum at each lake.

Following this in October 2010, Opus produced a Lake Generation Potential History report (Paine, 2010) of data series for the 10 largest hydro lakes. Lake levels were related to the amount of water stored in the lake, and then to potential power generation as this water is conveyed downstream through the various hydro stations. The total generation potential of water held in a particular lake is considered to be the sum of the energy generated as the water passes through all the dams downstream, and not just the one at the lake outlet. While the above analysis provides an index of the generation potential at any point in time, the total generation capacity in any given year is the sum of how many times water from the lake is drained and then refilled.

For the 2018 HMD update, the storage capacity history of the 10 largest hydro lakes has been updated to include data from 1 Jan 1980 to 31 Dec 2017. This could then be used to calculate potential generation from the capacity of the system using data from the infrastructure attributes HMD series.

There have been a number of changes to the various control structures and resource consents relating to the management of lake levels over time. This changes the capacity of the system. Therefore, this analysis of the potential generation only covers the period from 1 Jan 1980 to 31 Dec 2017. This 37 year period provides an appropriate length of record, and a valid basis for review.

With permission from Meridian Energy Ltd, Mighty River Power Ltd, and Contact Energy Ltd, lake level data have been retrieved from the Power Archive held by WSP Opus.

The lake level data used are those that have been edited and audited to ensure consistency and quality control before being appended to the Power Archive. However, it is periodically necessary to review and update these data when checking instrument calibrations, and adjusting datums to account for subsidence and other factors that affect relative water levels. These changes to the data over time usually only affect the more recent period of record.

It should be noted that the lake level recorded is a function of the interaction of a large number of variables. These variables include: rainfall, runoff, inflows, outflows, evaporation, lake level management for hydro power generation and flood mitigation, seiching (both natural and that caused by seismic activity), tectonic deformation and subsidence, wind build up, and wave action (both wind and boat generated). Lake levels therefore, rather than being a simple measure, actually reflect the integrated effect of a diverse range of controls.

2.1. Lake storage volume model

The following process was used to convert the lake level records to a time series of the variability of active lake storage volumes i.e. the capacity of the system, over time. For each of the ten lakes:

1. The lake level data was obtained.
2. Using a lake level–storage volume rating ‘curve’ provided by the generators, the lake level record was transformed to ‘active storage’ (millions of m^3).

The active storage was defined as that volume of water held above the minimum control level. Although the lakes also have maximum control levels, it was assumed that water above this level was still available to generate electricity. While there may be increased controls over the use of this water, in most situations the water is still used to generate electricity. Furthermore, even in the situation where this water may by-pass the first power station via spill flow, it may still be used to generate electricity in other structures downstream.

Any water in the lakes below the minimum control or operating level is treated as if it is not available for generation and therefore not “active storage”. In some situations this water can be used to generate electricity but there are usually constraints that must be overcome. An example of this is 'active contingent storage' which is available for some reservoirs, if they meet specific conditions. These constraints may relate to consent conditions, dam infrastructure and design, and environmental considerations. Because of the complexity of lake level management and power generation at low lake levels, it is simpler to assume no generation. This, however, results in the total generation potential provided by this analysis being conservative for a small percentage of time i.e., when the lake level is below the normal operating range. Lakes Wakatipu and Wanaka do not have operating ranges and thus the sill level and the base of the thalweg, respectively, were used as the level for zero generation.

2.2. North Island

Lake Taupo and Lake Waikaremoana are both located in the North Island (Figure 2.1). As of July 2016, Mercury Energy Ltd operates the Waikato hydro power scheme; they supersede Mighty River Power Ltd prior to this date. This consists of eight dams and nine power stations with flows from Lake Taupo managed via the control gates. Genesis Energy Ltd operates the Lake Waikaremoana scheme which consists of three power stations.

There are a number of other lakes that form part of various hydro schemes around the North Island. These, however, have not been included in this national overview and summary. This is because these lakes are small, usually contain only about 1-day's storage, are totally managed, and are often artificial (i.e., impounded river valleys) as opposed to natural water bodies.

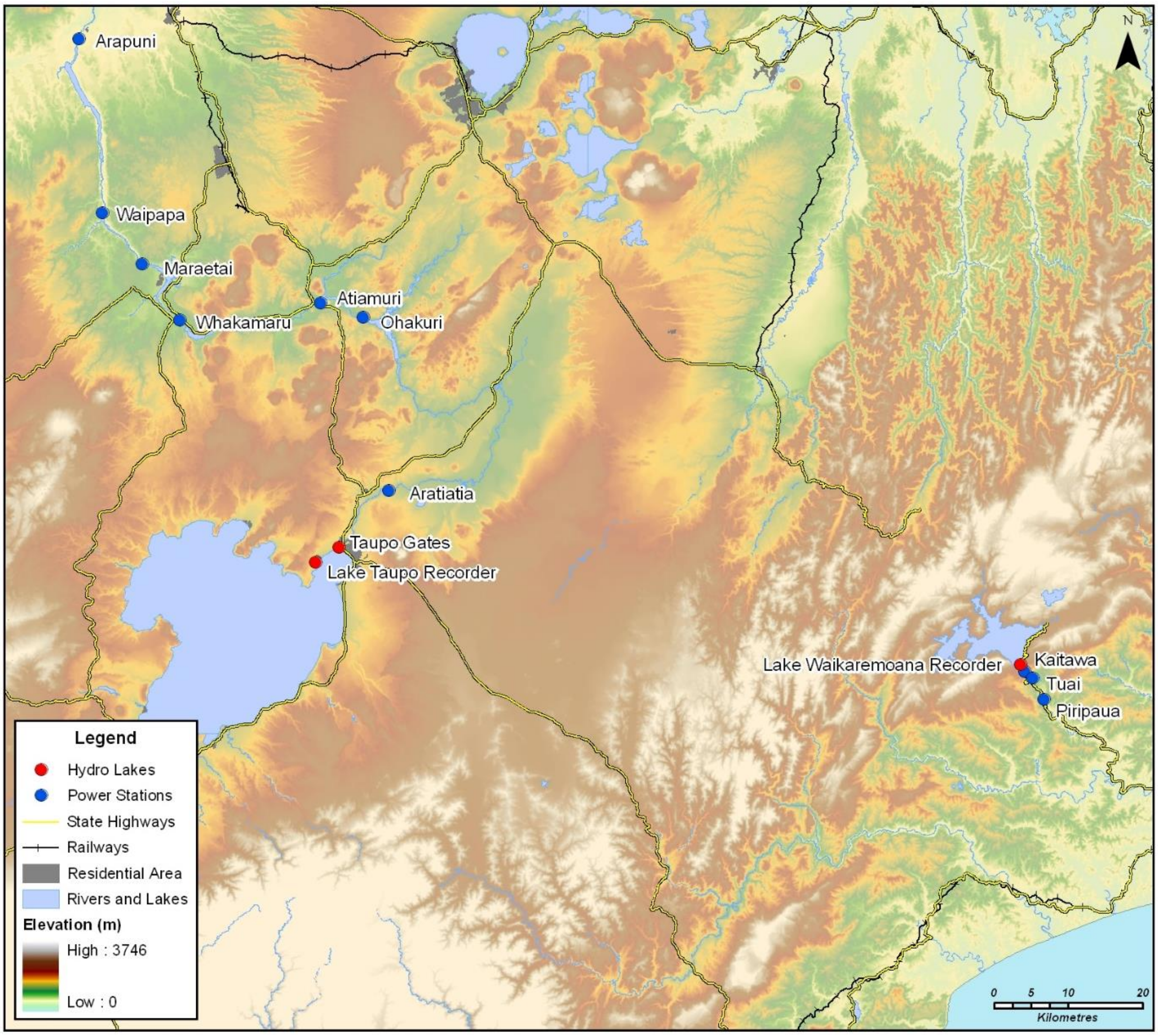

Figure 2.1: North Island hydro lakes part of the HMD storage and spill series

2.2.1. Lake Taupo

The conditions for the management of levels in Lake Taupo are set out in Environment Waikato's Resource Consent 105226 section 2:

2.2.1.1. Management of Lake Taupo

2.1) *The consent holder may at any time operate the Taupo gates to manage to level of Lake Taupo, for the purpose of water storage for hydro electricity generation, between the following control levels:*

357.25 masl (maximum control level), and

355.85 masl (minimum control level)

2.2) *The consent holder shall keep records of the levels of Lake Taupo and make them available to the Waikato Regional Council upon request. These levels shall be measured at the NIWA Acacia Bay lake level recording site, or at some alternative location approved in advance by Waikato Regional Council, and determined as a rolling average of levels taken over a 24 hour period.*

2.2.1.2. Minimum Outflow

2.3) *The minimum outflow from the Taupo Gates shall be 50m³/s determined as a rolling average of total gate flows taken over 30 minutes unless one of the Minimum Control Level conditions 2.8 or 2.9 applies.*

2.2.1.3. Maximum Control Level

2.4) *The Taupo Gates may not be used to manage the level of Lake Taupo above 357.25 masl primarily for the purposes of generating electricity. If at any time the lake rises above this level the Taupo gates shall be operated in such a way as to return the level of the lake to 375.25 masl as soon as is practicable.*

2.5) *The consent holder shall operate the Taupo gates according to a management regime designed to achieve the following objectives for the level of Lake Taupo:*

i. A less than 20% annual exceedance probability of 357.25 masl (i.e., an average 1 in 5 year recurrence interval).

ii. A less than 5% annual exceedance probability of 375.39 masl (i.e., an average 1 in 20 year recurrence interval).

iii. A less than 1% annual exceedance probability of 375.50 masl (i.e., an average 1 in 100 year recurrence interval).

2.6) *Within six months of the commencement of this consent the consent holder shall prepare a management plan that describes how Lake Taupo will be operated in order to meet the requirements of these consents. This plan shall incorporate all predictive and operational tools and methods that are employed to attain compliance with the objectives listed in condition 2.5 of these consents. This plan shall form part of the High Flow Management Plan by condition 5.2 of these consents.*

2.7) *The consent holder shall report annually to the Waikato Regional Council on its performance in managing the Taupo Gates in order to meet the objectives defined in condition 2.5 above.*

2.2.1.4. Minimum Control Level

2.8) *When the level of Lake Taupo is below 355.95 masl but above the minimum control level (355.85 masl), the Taupo gates will be operated so as to provide a flow sufficient to maintain an average flow at Karapiro that is between 140 m³/s and 150 m³/s, (determined as a rolling average of total station outflows taken over 30 minutes).*

2.9) *When the level of Lake Taupo is below 355.85 masl, Taupo outflows shall not exceed Taupo inflows and when, in these circumstances, Taupo inflows are sufficient to exceed the minimum flow at Karapiro, any such excess inflow shall be managed to raise the level of Lake Taupo above 355.85 masl.*

2.2.1.5. Exclusions

2.10) *The requirements of conditions 2.1, 2.3, 2.4, 2.5, 2.8, 2.9 and 3.20 shall not apply at any time when one or more of the following circumstances apply:*

i. *When the High Flow Management Plan described in condition 5.2 of this consent requires otherwise; or until that plan is operational, where the Waikato River Power Development Flood Management Rules dated November 2000 (or agreed amendment version) require otherwise;'*

ii. *When there is a threat to the structural integrity of the structures of the Waikato hydro system;*

iii. *When otherwise lawfully directed in writing by the Waikato Regional Council for flood management or Civil Defence purposes;*

iv. *When requested by the police, army, fire or other emergency service provider;*

v. *When necessary to respond to the uncontrolled release and spread of contaminants;*

vi. *Any force majeure event*

2.11) Where any of the circumstances listed in condition 2.10 occur (or there is a reasonable expectation that one may occur) the consent holder shall, as soon as practicably possible, advise the Waikato Regional Council and other parties who may reasonably be expected to be directly affected by the excursion from the normal operating regime, of the circumstances, the action being taken and its likely duration.

2.12) Where an excursion from the defined operating regime occurs due to any of the circumstances described in condition 2.10, the consent holder shall return the system to normal operating regime as soon as practicably possible.

2.13) Within four weeks of the system being returned to normal operation a report shall be provided to the Waikato Regional Council describing the nature and duration of the excursion event and the ways in which the hydro system was operated outside the normal requirements of this consent.

Table 2.1 lists characteristics of Lake Taupo including the maximum and minimum control levels and lake area. The associated storage volumes are listed in the hydrological constraints dataset. The large size of Lake Taupo means that a constant area was assumed for the lake storage rating and are listed in Table 2.2. A linear lake level–lake area rating was used to calculate the lake storage volumes which is also listed in Table 2.2.

Table 2.1: Characteristics of Lake Taupo

LAKE TAUPO	
Lake area (km²)	611.00
Maximum operating level (masl)	357.25
Minimum operating level (masl)	355.85
Storage = (LakeLevel * 611) - 217424	

Table 2.2: Lake Taupo Level-Area-Storage rating

LEVEL (M)	AREA (KM²)	STORAGE (MM³)
355.85	611	0.00
356.00	611	91.65
356.20	611	213.85
356.40	611	336.05
356.60	611	458.25
356.80	611	580.45
357.00	611	702.65
357.25	611	855.40

2.2.2. Lake Waikaremoana

Lake Waikaremoana currently has an operating regime of three metres, from 580.29 to 583.29 masl (Moturiki Datum). Genesis Energy operates to specific consent conditions that control discharges from Lake Waikaremoana above and below this operating range.

Table 2.3 shows the characteristics of Lake Waikaremoana, including the maximum and minimum storage volumes. The associated storage volumes are listed in the hydrological constraints dataset. A linear lake level–lake area rating was used to calculate the lake storage volumes, key values are listed in Table 2.4.

There are a number of gaps in the lake level dataset and therefore also in the storage volume dataset. Any gaps less than 24-hours were removed but any greater than 24-hours were left.

Table 2.3: Characteristics of Lake Waikaremoana

LAKE WAIKAREMOANA	
Lake area (km²)	54.00
Maximum operating level (masl)	583.29
Minimum operating level (masl)	580.29
Storage = (LakeLevel * 52.407) - 30411	

Table 2.4: Lake Waikaremoana Level-Area-Storage rating

LEVEL (M)	AREA (KM²)	STORAGE (MM³)
580.29	51.85	0.00
580.60	51.96	16.11
580.80	52.02	26.51
581.00	52.09	36.93
581.20	52.16	47.36
581.40	52.22	57.81
581.60	52.29	68.26
581.80	52.36	78.73
582.00	52.42	89.22
582.20	52.49	99.72
582.40	52.56	110.23
582.60	52.62	120.75
582.80	52.69	131.29
583.00	52.75	141.84
583.20	52.82	152.40
583.29	52.85	157.16

2.3. South Island

A total of eight lakes were reviewed in the South Island. Lakes Ohau, Tekapo and Pukaki are part of the Waitaki scheme; and Te Anau and Manapouri make up the Waiau scheme; both schemes are operated by Meridian Energy with the exception of Lake Tekapo. Lake Hawea is managed by Contact Energy, and the natural Lakes Wanaka and Wakatipu were also studied. Figure 2.2 shows the locations of these lakes.

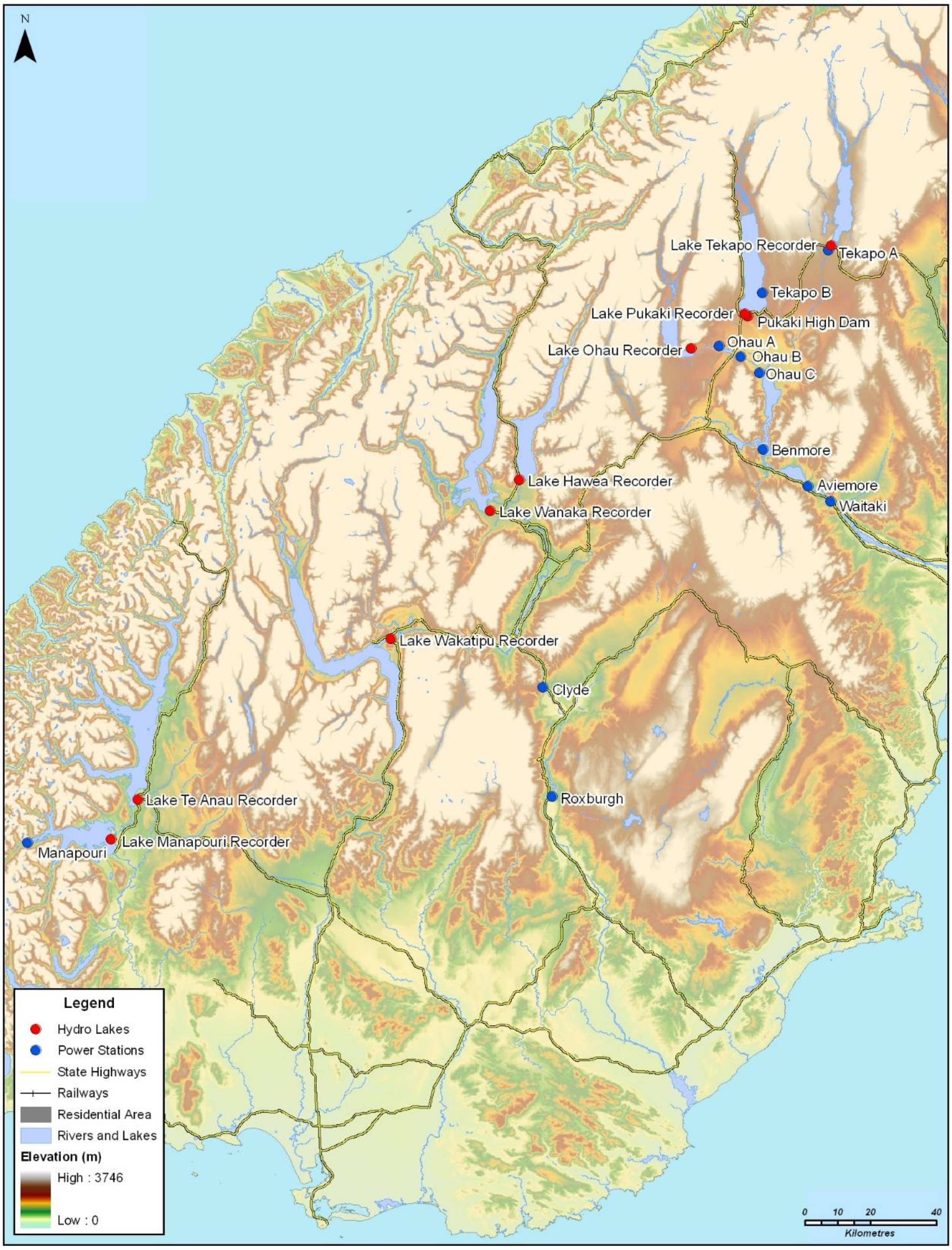

Figure 2.2: South Island hydro lakes part of the HMD storage and flow series

2.3.1. Lake Tekapo

The consented minimum control level for Lake Tekapo is 701.8 masl. However, from 1 October to the following 31 March the effective minimum control level is 704.1 masl. Water below 704.1 masl can be used, however, only according to condition 14 Resource Consent number CRC905302.0 (Canterbury Regional Council):

(a) *From 1 October to the following 31 March the minimum operating level for Lake Tekapo shall not decrease below 704.1m amsl except during any period during which the Electricity Commission (or any statutory body exercising like powers and functions to the Electricity Commission) determines:*

(i) *That reserve generation capacity (such as Whirinaki Power Station) is required to generate electricity; or*

(ii) *The National or South Island min zones (or their future equivalents) have been breached.*

(b) *The Grantee shall restore the level of Lake Tekapo to above 704.1m as soon as practicable and shall advise the Water Resources Manager, Canterbury Regional Council, weekly of strategies adopted until the lake level is restored to above 704.1m.*

(c) *The Grantee shall provide evidence that the circumstances set out in (i) exist to the Canterbury Regional Councils RMA Compliance and Enforcement Manager*

This means that Tekapo has ‘active contingent storage’ available, if the above requirements are met. Therefore, some years this is available for generation, and is calculated separately in the dataset from the ‘active’ storage.

The maximum control level of Lake Tekapo varies throughout the year as shown in Table 2.5.

Table 2.5: Maximum control levels for Lake Tekapo

MAXIMUM CONTROL LEVEL (M)	MONTHS
710.9	June to July
710.6	May
710.3	April and August
710.0	March
709.7	September to February

Table 2.6 provides a summary of the variability in the storage of water held in Lake Tekapo, including the consented and operating levels as well as the lake area. The associated active storage volumes are listed in the hydrological constraints dataset. A polynomial lake level–lake area rating was used to calculate the lake storage volumes, key values including both summer and winter equations are listed in Table 2.7.

Table 2.6: Characteristics of Lake Tekapo

LAKE TEKAPO	
Lake area (km²)	97.5
Normal operational maximum level (m)	709.7
Normal operational minimum levels (m)	702.1
March – October	701.8
October - March	704.1
Consented minimum level (m)	701.8
Winter Storage = (-0.0120654091 * (Lake Level^3)) + (26.6378593716 * (LakeLevel^2)) - (LakeLevel * 19481.175113337) + 4722566.45591556	
Summer Storage = ((-0.0120654091 * (Lake Level^3)) + (26.6378593716 * (LakeLevel^2)) - (LakeLevel * 19481.175113337) + 4722566.45591556) -191	

Table 2.7: Lake Tekapo Level-Area-Storage rating

LEVEL (M)	AREA (KM²)	STORAGE (MM³)
701.80	80.25	0.00
702.10	80.98	24.19
702.33	81.55	42.96
702.50	81.96	56.77
703.00	83.16	98.05
703.50	84.34	139.92
704.00	85.50	182.38
704.50	86.65	225.42
705.00	87.78	269.03
705.50	88.89	313.20
706.00	89.98	357.91
706.50	91.05	403.17
707.00	92.11	448.96
707.50	93.15	495.28
708.00	94.17	542.11
708.50	95.17	589.44
709.00	96.15	637.28
709.50	97.12	685.60
709.70	97.50	705.06
710.00	98.07	734.39
710.50	99.00	783.66
711.00	99.91	833.39
711.50	100.80	883.56
712.00	101.68	934.18
712.50	102.54	985.24
712.88	103.17	1023.91
712.94	110.59	1030.31
713.36	111.61	1074.45
714.28	114.10	1170.26
715.25	116.72	1273.79
715.80	118.02	1332.72

2.3.2. Lake Pukaki

The consented minimum control level for Lake Pukaki is 518.0masl. The maximum control level varied throughout the year until 11 Sep 2012 as detailed in Table 2.8. Since 11 Sep 2012 the maximum control level is now 532.5m year-round.

Table 2.8: Maximum control levels for Lake Pukaki until 11 Sep 2012

MAXIMUM CONTROL LEVEL (M)	MONTHS
532.5	May to August
532.0	September to April

Lake Pukaki also has a separate consented contingent storage, where the lake can be lowered further and the available storage used for generation. This is the ‘active contingent storage’ available. Therefore, some years this is available for generation, and is calculated separately in the dataset from the ‘active’ storage.

Table 2.9 shows the characteristics of Lake Pukaki, including the levels and lake area. The associated storage volumes are listed in the hydrological constraints dataset. A polynomial lake level–lake area rating was used to calculate the lake storage volumes, key values are listed in Table 2.10.

Table 2.9: Characteristics of Lake Pukaki

LAKE PUKAKI	
Lake area (km²)	178.70
Normal operational maximum level (m)	532.00
Normal operational minimum level (m)	518.20
Consented minimum level (m)	518.00
Maximum storage (million m³) - at normal operational maximum level	2335.92
Minimum storage (million m³) - at consented minimum level	0.00

Storage = (0.8383 * (LakeLevel^2)) - (LakeLevel * 713.36) +144584

Table 2.10: Lake Pukaki Level-Area-Storage rating

LEVEL (M)	AREA (KM^2)	STORAGE (MM^3)
518.00	154.47	0.00
518.20	154.84	30.93
520.00	158.14	312.62
522.00	161.74	632.51
524.00	165.27	959.52
526.00	168.72	1293.51
528.00	172.10	1634.34
530.00	175.41	1981.85
532.00	178.66	2335.92
532.50	179.46	2425.45
534.00	181.83	2696.42
536.00	184.94	3063.18
538.00	187.98	3436.10

2.3.3. Lake Ohau

The operating range for Lake Ohau is between 519.45m and 520.25m. Lake Ohau is essentially managed as a ‘run of the river’ scheme because it has a weir at the outflow instead of control gates. Though Lake Ohau is consented for contingent storage, because of the weir at the outflow this ‘active contingent storage’ isn’t used as such, and is therefore not separated like other lakes with this type of consented contingent storage.

Table 2.11 shows the characteristics of Lake Ohau, including the levels and lake area. The associated storage volumes are listed in the hydrological constraints dataset. A linear lake level–lake area rating was used to calculate the lake storage volumes, key values are listed in Table 2.12.

Table 2.11: Characteristics of Lake Ohau

LAKE OHAU	
Lake area (km^2)	61.20
Normal operational maximum level (m)	520.25
Normal operational minimum level (m)	519.75
Consented minimum level (m)	519.45
Storage = (LakeLevel * 62.181) - 32300	

Table 2.12: Lake Ohau Level-Area-Storage rating

LEVEL (M)	AREA (KM^2)	STORAGE (MM^3)
519.45	60.23	0.00
519.60	60.51	9.80
519.75	60.78	18.92
519.90	61.06	28.08
520.05	61.33	37.28
520.20	61.61	46.52
520.25	61.70	49.60
520.35	61.89	55.79
520.50	62.16	65.15
520.65	62.44	74.48
520.80	62.71	83.89
520.95	62.99	93.34
521.10	63.27	102.83
521.25	63.54	112.36

2.3.4. Lake Te Anau

Lake Te Anau is a storage component in the Manapouri Power Scheme (MPS) water balance, although the rapid turnover of water through the lake means that the total volume of water that can be stored for later electricity generation purposes is small.

Lake Te Anau fluctuates because of natural variations in inflow, and the controlled outflow via the Te Anau Lake Control Structure (TLC) to the Upper Waiau River. Under the Lake Operating Guidelines, the duration, rate, and return period of fluctuations is controlled to mimic, as far as possible, the natural lake level variations that occurred prior to the development of the power scheme. Operating ranges defined in the Guidelines for Lake Te Anau are as follows:

- *High Range*: above 202.7 m
- *Main Range*: between 202.7 m and 201.5 m
- *Low Range*: below 201.5 m

The top of the Main Range (202.7m) is also known as the maximum control level and the bottom of the Main Range (201.5m) is the minimum control level (Meridian, 2009).

However, the flood rules do not start to be applied at the maximum control level (top of the Main Range). They come into effect at a level of 203.3m, which is 0.6m into the high range. There are also further complications in relation to the high and low ranges as set out in the Manapouri-Te Anau Development Act (Operating Guidelines) (Appendix A). Within the high range (above the 'maximum control level') there are certain ranges which the lake level can reside. However, the lake cannot be static at any of these ranges, and there are maximum durations over which any particular lake level can remain stable.

For this report, the maximum operating level is 202.7m, and the minimum operating level is 201.5m, in accordance with the Main Range set out in the Act. However, the absolute minimum level of 200.86m is used by Meridian Energy as the lower limit in their calculations. At this level they are only able to release a volume of water equal to the inflow to the lake.

Table 2.13 shows the characteristics of Lake Te Anau used in the analysis, including the levels and lake area. The associated storage volumes are listed in the hydrological constraints dataset. A large part of Lake Te Anau has vertical walls which produce a near-straight line, thus, a constant area was assumed for the lake storage rating. A linear lake level–lake area rating was used to calculate the lake storage volumes, key values are listed in Table 2.14.

Table 2.13: Characteristics of Lake Te Anau

LAKE TE ANAU	
Lake area (km²)	352.00
Maximum operating level (m)	202.70
Minimum operating level (m)	201.50
Absolute minimum (m)	200.86
Storage = (LakeLevel * 352) - 70703	

Table 2.14: Lake Te Anau Level-Area-Storage rating

LEVEL (M)	AREA (KM²)	STORAGE (MM³)
200.86	352.00	0
201.00	352.00	49.28
201.50	352.00	225.28
202.00	352.00	401.28
202.50	352.00	577.28
202.70	352.00	647.68
203.00	352.00	753.28

2.3.5. Lake Manapouri

Lake Manapouri fluctuates because of natural variations in inflow, and the controlled outflow via the Manapouri Lake Control Structure (MLC), just downstream of the confluence of the Mararoa and Lower Waiau Rivers. The Manapouri Power Scheme (MPS) has operated under Lake Operating Guidelines developed by the Lakes Guardians since 1977. These Guidelines were incorporated into the Manapouri-Te Anau Development Act 1963 (MTADA) in 1981. The first version of these Guidelines was published in the *New Zealand Gazette* on 3rd December 1981. The guidelines have been amended several times subsequently.

The aim of the Lake Operating Guidelines is to protect the existing patterns, ecological stability, and recreational values of their "vulnerable shorelines, and to optimise the energy output of the Manapouri power station". The Guidelines set out limits on the frequency, duration, and return period for the lake levels by describing low, main, and high ranges. The Guidelines also outline "Gate Opening and Closing Procedures" that are applicable to the MLC and TLC structures.

Operating ranges defined in the Guidelines for Lake Manapouri are:

- *High Range*: above 178.6m
- *Main Range*: between 176.8m and 178.6m
- *Low Range*: below 178.6

The top of the Main Range (178.6m) is also known as the maximum control level and the bottom of the Main Range (176.8m) as the minimum control level (Meridian, 2009).

Like Lake Te Anau, Lake Manapouri has a complicated system governing the control levels (Appendix A). Within the high range (above the 'maximum control level') there are certain ranges within which the lake level can reside. However, the lake cannot be static at any of these ranges, and there are maximum durations over which any particular lake level can remain stable.

For this report, the maximum operating level is 178.6m and the minimum operating level is 176.8m. This is consistent with the Main Range set out in the Manapouri-Te Anau Development Act (Operating Guidelines) (Appendix A). However, the absolute minimum level of 175.86 is used by Meridian Energy as the lower limit in their calculations. At this level they are only able to generate using a volume of water equal to lake inflow.

Table 2.15 shows the characteristics of Lake Manapouri used in this analysis; including the levels and lake area. The associated storage volumes are listed in the hydrological constraints dataset. A linear lake-level area rating was used to calculate the lake storage volumes, key values are listed in Table 2.16.

Table 2.15: Characteristics of Lake Manapouri

LAKE MANAPOURI	
Lake area (km²)	141.00
Maximum operating level (m)	178.60
Minimum operating level (m)	176.80
Absolute minimum level (m)	175.86
Storage = (LakeLevel * 139.34) - 24506	

Table 2.16: Lake Manapouri Level-Area-Storage rating

LEVEL (M)	AREA (KM²)	STORAGE (MM³)
175.86	141.00	0.00
176.80	141.00	129.79
177.00	141.00	157.55
177.20	141.00	185.37
177.40	141.00	213.24
177.60	141.00	241.16
177.80	141.00	269.13
178.00	141.00	297.16
178.20	141.00	325.24
178.40	141.00	353.37
178.60	141.00	381.55

2.3.6. Lake Hawea

The consented minimum control level for Lake Hawea is 338m. However, this can be lowered to 336m (previously 330m) when the Electricity Authority determines that reserve generation should be used i.e. it has a consented ‘contingent storage’. This is calculated separately from the ‘active storage’ that is available in the storage dataset. The maximum control level is 346m. This can, however, be exceeded under the Flood Management Plan.

Table 2.17 shows the characteristics of Lake Hawea including the levels and lake area. The associated storage volumes are listed in the hydrological constraints dataset. A polynomial lake level–lake area rating was used to calculate the lake storage volumes, key values are listed in Table 2.18.

Table 2.17: Characteristics of Lake Hawea

LAKE HAWEA	
Lake area (km^2)	141.7
Maximum operating level (m)	346.0
Minimum operating level (m)	338.0
Storage = (0.939500 * (LakeLevel^2)) - (LakeLevel * 500.21) +62758.0	

Table 2.18: Lake Hawea Level-Area-Storage rating

LEVEL (M)	AREA (KM^2)	STORAGE (MM^3)
338.00	134.42	0
338.50	135.36	67.49
339.00	136.30	135.46
339.50	137.24	203.89
340.00	138.18	272.79
340.50	139.12	342.16
341.00	140.06	412.00
341.50	141.00	482.31
342.00	141.94	553.10
342.50	142.88	624.35
343.00	143.82	696.07
343.50	144.76	768.26
344.00	145.70	840.92
344.50	146.64	914.05
345.00	147.58	987.65
345.50	148.51	1061.72
346.00	149.45	1136.26

2.3.7. Lake Wanaka

Lake Wanaka is a natural lake, with no control structure. It therefore does not have any consent conditions that manage water levels. It does, however, impact on the Clutha at Cardrona Confluence consent (Permit No. 2001.392 8c) where the flow cannot exceed 800m^3/s except when flood emergency conditions prevail. Contact Energy treat the ‘normal operating range’ of Lake Wanaka as 276.35m to 278.00m (Table 2.19).

Table 2.19: ‘Operating’ levels Lake Wanaka

LAKE WANAKA	
Minimum	276.35
Maximum	278.00

At the ‘minimum operating level’, water is still being discharged and can be used for generation. Therefore, the thalweg level (275.40m) at the lake outlet was taken to have storage of 0m^3. At the ‘minimum operating level’ there is still estimated to be 183.35 million m^3 of storage.

Table 2.20 shows the characteristics of Lake Wanaka used in this analysis, including the levels and lake area. The associated storage volumes are listed in the hydrological constraints dataset. The large size of Lake

Wanaka means that a constant area was assumed for the lake storage rating. A linear lake level–lake area rating was used to calculate the lake storage volumes, key values ae listed in Table 2.21.

Table 2.20: Characteristics of Lake Wanaka

LAKE WANAKA	
Lake area (km²)	193.00
Maximum 'operating level' (m)	278.00
Minimum 'operating level' (m)	276.35
Storage = (LakeLevel * 193) - 53152	

Table 2.21: Lake Wanaka Level-Area-Storage rating

LEVEL (M)	AREA (KM²)	STORAGE (MM³)
275.40	193.00	0.00
275.60	193.00	38.60
275.80	193.00	77.20
276.00	193.00	115.80
276.20	193.00	154.40
276.35	193.00	183.35
276.40	193.00	193.00
276.60	193.00	231.60
276.80	193.00	270.20
277.00	193.00	308.80
277.20	193.00	347.40
277.40	193.00	386.00
277.60	193.00	424.60
277.80	193.00	463.20
278.00	193.00	501.80

2.3.8. *Lake Wakatipu*

Lake Wakatipu is an uncontrolled lake, with no operating levels. Contact Energy use levels 309.60 and 310.80m for internal reporting regarding active storage. These numbers are adopted here as the minimum and maximum 'operating levels' for consistency with information from Contact Energy.

Table 2.22 shows the characteristics of Lake Wakatipu used in the analysis, including the levels and lake area. The associated storage volumes are listed in the hydrological constraints dataset. The large size of Lake Wakatipu means that a constant area was assumed for the lake storage rating. A linear lake level–lake area rating was used to calculate the lake storage volumes, key values are listed in Table 2.23).

At the minimum 'operating' level, water is still being discharged and can be used for generation. Therefore, a lake level equal to the sill elevation (308.83m) at the lake outlet was taken to imply a storage capacity of 0m³. At the minimum 'operating' level there is 222.53 million m³ of storage.

Table 2.22: Characteristics of Lake Wakatipu

LAKE WAKATIPU	
Lake area (km²)	293.00
Maximum 'operating' level (m)	310.80
Minimum 'operating' level (m)	309.60
Storage = (LakeLevel * 289) - 89252	

Table 2.23: Lake Wakatipu Level-Area-Storage rating

LEVEL (M)	AREA (KM²)	STORAGE (MM³)
308.83	293.00	0.00
309.00	293.00	49.13
309.20	293.00	106.93
309.40	293.00	164.73
309.60	293.00	222.53
309.80	293.00	280.33
310.00	293.00	338.13
310.20	293.00	395.93
310.40	293.00	453.73
310.60	293.00	511.53
310.80	293.00	569.33

3. Spill volumes

To calculate potential generation, spill volumes from each of the major infrastructure are required. Spill flows that bypass generators do not generate power and therefore should not be included in potential generation.

There are many reasons for hydrological spill flow, Meridian Energy have split these into 11 categories:

- Plant
- Obstruction
- High flow
- Regulatory
- Contractual
- Recreation
- Cost
- Economic
- Transmission constraint
- Hydraulic constraint
- Other

Meridian has definitions of these spill flow categories on their website (https://www.meridianenergy.co.nz/assets/About-us/Our-power-stations/Lake-levels/Hydro-Spill-Definition-of-Terms.pdf).

Weekly spill volumes from 1 Jan 1980 to 31 Dec 2017 are included as part of this HMD update. With permission from Meridian Energy Ltd, Mighty River Power Ltd, and Contact Energy Ltd, spill data was retrieved from the Power Archive held by Opus. The spill volumes for Lake Tekapo and Lake Waikaremoana have been received from Genesis Energy. The spill volumes were transformed to be 1-week average values for the HMD.

There were a number of gaps in these datasets. Gaps that were smaller than 24-hours were removed but longer gaps were kept in the datasets. These gaps have a ‘null’ value filed for the time step and a quality code of ‘100’ applied to the period of missing record.

The spill data are calculated for weeks from Monday to Sunday and are recorded at 24:00 on the last day of the week. Therefore, the first weekly spill data for sites starting in 1980 begins on 31 December 1979 at 00:00 and runs to 6 January 1980 at 24:00.

3.1. North Island

3.1.1. Waikato Power Scheme

Weekly spill volumes for each of the major dams in the Waikato Power Scheme are included in the HMD: Lake Taupo; Lake Aratiatia; Lake Ohakuri; Lake Atiamuri; Lake Whakamaru; Lake Maraetai; Lake Waipapa; Lake Arapuni; and Lake Karapiro. Lake Taupo weekly outflows have also been included as all outflows from Lake Taupo through the control gates are technically spill flows.

This spill data, collected by Mercury, is the best data available at this time. The quality of this data is not guaranteed and therefore should be used accordingly.

3.1.2. Waikaremoana Power Scheme

Weekly ‘spill’ volumes for each of the major dams in the Waikaremoana Scheme are included in the HMD: Lake Waikaremoana – Onepoto; Waikaretaheke River at Piripaua; and Waikaretaheke River at Upstream Mangaone.

Lake Waikaremoana – Onepoto is the spill from Lake Waikaremoana which can be either operational or regulatory. The lake level (max control level) could be used to determine whether the spill is regulatory or not.

The Waikaretaheke River at Piripaua and Waikaretaheke River at U/S Mangaone flow records can be used to determine the spill flows from Lake Kaitawa and Lake Whakamarino. Waikaretaheke River at Piripaua shows the spill from either Lake Kaitawa or Lake Whakamarino, as it is situated below the Waikaretaheke Diversion and the Whakamarino spillway. Waikaretaheke at U/S Mangaone shows the natural and spill flow from Lake Kaitawa. Any flows above ~6m³/s at the Waikaremoana River at U/S Mangaone flow site is most likely spill from Lake Kaitawa; it has a baseflow of approximately 0.8-0.9m³/s. The flows can be separated from the U/S Mangaone site from the Piripaua site to determine when there is spill at Lake Kaitawa, and when the spill is from Lake Whakamarino. The exception is under high rainfall conditions, which will cause natural inflow below the Waikaretaheke diversion, resulting in flow measured at the Piripaua site.

This spill data, collected by Genesis Energy Ltd, is the best data available at this time. The quality of this data is not guaranteed and therefore should be used accordingly. Not all datasets begin in 1980 and consequently have different start dates to some other datasets.

3.2. South Island

3.2.1. Waitaki Power Scheme

Weekly spill volumes for each of the major dams in the Waitaki Power Scheme are included in the HMD: Lake Tekapo Gate 17; Lake George Scott – Tekapo River; Lake Pukaki; Lake Ohau; Lake Ruataniwha; Lake Benmore; Lake Aviemore; and Lake Waitaki.

Lake Tekapo Gate 17 data is the spill data from Lake Tekapo that by passes only Tekapo A Power Station. Lake George Scott – Tekapo River is the spill data from Lake Tekapo that bypasses Tekapo A and B Power Stations and well as Ohau A, B and C Power Stations.

3.2.2. Manapouri Power Scheme

Weekly spill volumes for each of the major dams in the Manapouri Power Scheme are included in the HMD: Lake Te Anau; and Lake Manapouri. Lake Te Anau weekly outflows have been included as all outflows from Lake Te Anau through the control gates are technically spill flows.

3.2.3. Clutha Power Scheme

Weekly spill volumes for each of the major dams in the Clutha Power Development are included in the HMD: Lake Hawea; Lake Dunstan; and Lake Roxburgh. Lake Hawea weekly outflows have been included as all outflows from Hawea through the control gates are technically spill flows.

4. References

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