OPUS

Hydrological Modelling Dataset - Interim Update

Report 3: Storage and Spill Series Descriptions

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3-53203.16	2016.2	30 June 2016	Interim update 2016 – final for publication
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Preface

A large proportion of New Zealand's electricity needs is 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) contains hydrological information made available by the Electricity Authority. The dataset was known as SPECTRA 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 decision-making.

The HMD is comprised of data provided by hydro generators, supplemented by 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 provides inflows for reservoirs and flows at various existing or potential hydro generating sites.

3. Storage and spill;

   This time series indicates 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) interim update was requested by the Electricity Authority and includes data to 31 December 2016. This report provides a description of how the spill and lake storage volumes are derived.

An interim update adds one year of data to the end of the previous full HMD update, whereas a full update recalculates all data back to 1932. This interim update adds data from 1 January 2016 to 31 December 2016, with no re-calculation of the historic datasets.

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 on hydrological controls of schemes, usually via consent conditions. This was completed for the power stations associated with the 10 largest reservoirs.

- Actual Flows:

  a) 'Actual' inflows to or outflows from a number of reservoirs in New Zealand. The inflows are modelled, while the outflows are generally measured;
  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 used for hydro-power generation at some stage in the future.

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

- Natural flows:

  a) 'Natural' uncontrolled inflows to a number of reservoirs;
  b) Modelled natural inflows or tributary inflows to reservoirs, as though they are uncontrolled; and
  a) River flows at gauging stations which could be used for hydro-power generation at some stage in the future.

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

- Lake storage

  Daily usable storage volumes from 1980 to 2016 for the 10 largest reservoirs.

- Spill volume

Weekly spill volume data for each of the structures downstream of the 10 largest reservoirs.

The lake storage, spill volumes, infrastructure attributes, and hydrological attributes were produced for the first time in 2016.

The following Power Companies have provided data for the spill and lake storage volume datasets:

- Contact Energy Ltd
- Genesis Energy Ltd
- Meridian Energy Ltd
- Mercury Ltd

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

1.1 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 to 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 datasets are still generally collectively referred to as the ‘Power Archive’.

1.2 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 of each environmental standard; the degree of rigour to which the standard is applied affects the final quality of the data.

It was recommended that these standards be 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. This 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' the data requires each component of the standard to be practised; from data collection through to archiving.

The NQCS can be introduced in its basic form, or it can be expanded 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 spill volume datasets have been coded as '200', because the quality of this data is not defined. 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 a gap is filled with correlation with a nearby flow site. The codes '320' and '325' represent data that has been synthesized, usually from calculations or models. The '330' code denotes that the data has been entered as the median flow, for example, gaps in the Lake Waikaremoana inflow were filled with the median flow and coded as such. The '340' code is used when the data has been 'replicated'. This may occur when whole or parts of years were replicated and entered to fill a period of missing record. This occurred often between 1931 and 1934 when there were a limited number of flow sites operating. The last code is '350' where the data is of 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	Synthesized via calculations or models (Opus)
325	Synthesized by the recording authority
330	Median flow
340	Replicated data
350	Unknown origin

1.3 Dataset summary

1.3.1 Data Sources

The HMD 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 lists the source of the record for each series and period. The quality code for record is listed along with the definition of the quality code (Table 1.1).

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

Dataset	Period	Quality Code	Code Definition
Lake Taupo Spill	01/01/80 - 31/12/16	200	Not defined for this update
Lake Taupo Storage	01/01/80 - 31/12/16	320	Synthetic – Synthesized (Opus)
Lake Waikaremoana Spill	01/01/80 - 31/12/16	200	Not defined for this update
Lake Waikaremoana Storage	01/01/80 - 31/12/16	320	Synthetic – Synthesized (Opus)
Lake Ohau Spill	01/01/80 - 31/12/16	200	Not defined for this update
Lake Ohau Storage	01/01/80 - 31/12/16	320	Synthetic – Synthesized (Opus)
Lake Tekapo Spill	01/01/80 - 31/12/16	200	Not defined for this update
Lake Tekapo Storage	01/01/80 - 31/12/16	320	Synthetic – Synthesized (Opus)
Lake Pukaki Spill	01/01/80 - 31/12/16	200	Not defined for this update
Lake Pukaki Storage	01/01/80 - 31/12/16	320	Synthetic – Synthesized (Opus)
Lake Wanaka Spill	01/01/80 - 31/12/16	200	Not defined for this update
Lake Wanaka Storage	01/01/80 - 31/12/16	320	Synthetic – Synthesized (Opus)
Lake Hawea Spill	01/01/80 - 31/12/16	200	Not defined for this update
Lake Hawea Storage	01/01/80 - 31/12/16	320	Synthetic – Synthesized (Opus)
Lake Wakatipu Spill	01/01/80 - 31/12/16	200	Not defined for this update
Lake Wakatipu Storage	01/01/80 - 31/12/16	320	Synthetic – Synthesized (Opus)
Lake Te Anau Spill	01/01/80 - 31/12/16	200	Not defined for this update
Lake Te Anau Storage	01/01/80 - 31/12/16	320	Synthetic – Synthesized (Opus)
Lake Manapouri Spill	01/01/80 - 31/12/16	200	Not defined for this update
Lake Manapouri Storage	01/01/80 - 31/12/16	320	Synthetic – Synthesized (Opus)

2 Lake Storage

In February 2009, 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) and 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 2017 HMD interim update, the storage history of the 10 largest hydro lakes has been updated to include data from 1 Jan 1980 to 31 Dec 2016. This could then be used to calculate potential generation 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. Therefore, this analysis of the potential generation only covers the period from 1 Jan 1980 to 31 Dec 2016. This 36 year period provides an appropriate length of record, and a valid basis for review.

With permission from Meridian Energy Ltd, Mercury Ltd, and Contact Energy Ltd, lake level data have been retrieved from the Power Archive held by 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 over time. For each of the ten lakes:

1. The lake level data was obtained; and

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). Each of the lakes have a linear volume rating 'curve' with the exception of Tekapo and Pukaki which have a polynomial equation.

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. 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 Ltd operates the Waikato hydro power scheme; it was Mighty River Power Ltd prior to this date. Waikato hydro scheme 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.

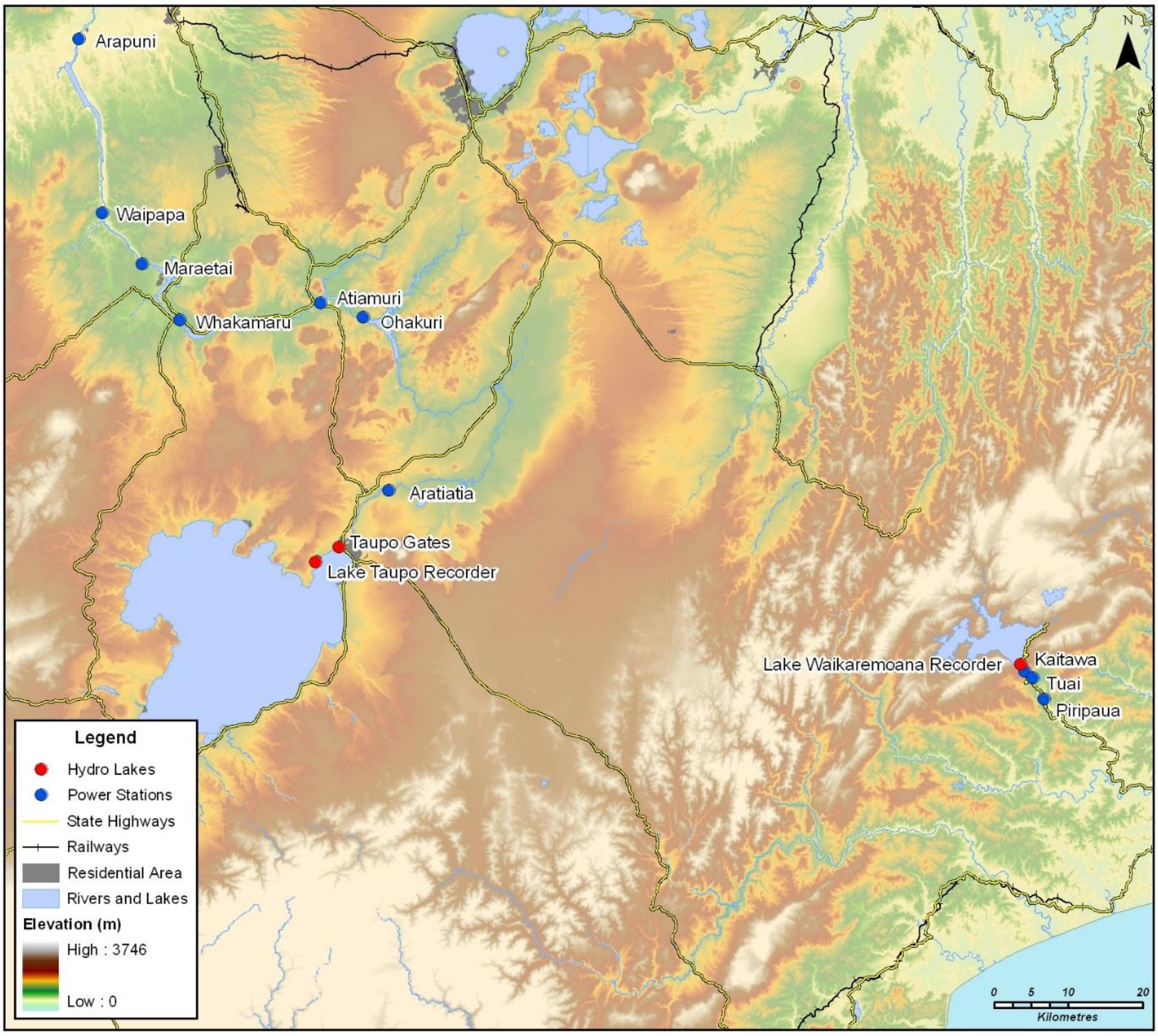

Figure 2.1: North Island hydro lakes part of the HMD storage and spill series

2.2.1 Lake Taupo

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

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.*

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.*

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.*

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.*

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. A linear lake level–lake area rating was used to calculate the lake storage volumes; with key values listed in Table 2.2.

Table 2.1: Characteristics of Lake Taupo

Lake area (km^2)	611.00
Maximum operating level (masl)	357.25
Minimum operating level (masl)	355.85

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 range 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; with key values 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 those greater than 24-hours were left.

Table 2.3: Characteristics of Lake Waikaremoana

Lake area (km²)	54.00
Maximum operating level (masl)	583.29
Minimum operating level (masl)	580.29

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 (operated by Genesis Energy Ltd). 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.

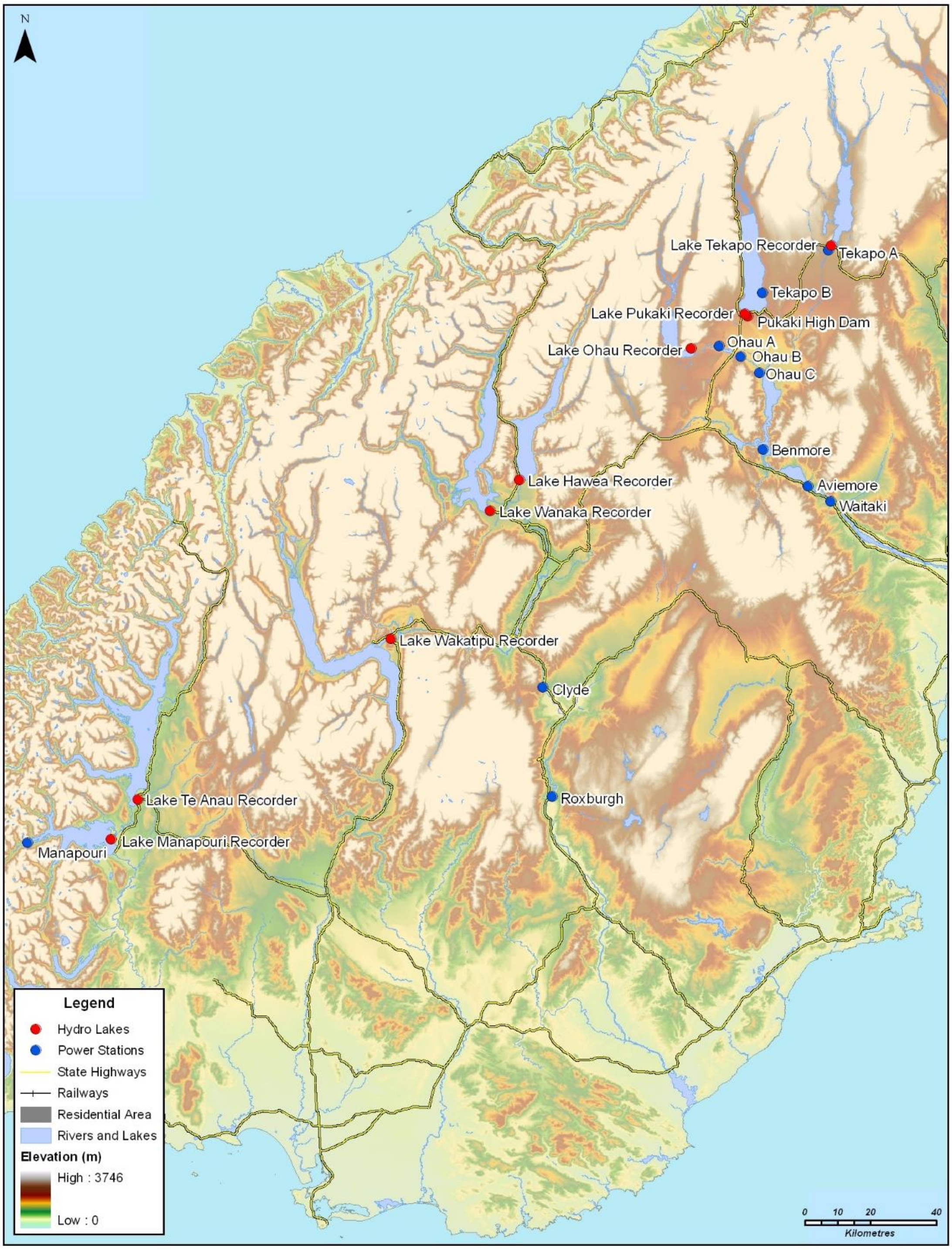

Figure 2.2: South Island hydro lakes part of the HMD storage and flow series

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

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 storage volumes are listed in the hydrological constraints dataset. A polynomial lake level–lake area rating was used to calculate the lake storage volumes, with key values listed in Table 2.7.

Table 2.6: Characteristics of 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

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

Level (m)	Area (km²)	Storage (Mm³)
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 has been 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

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, with key values listed in Table 2.10.

Table 2.11 shows the polynomial lake level-lake area rating that is used to calculate the contingent storage of the lake when it is lowered below 518.0m (to a minimum of 513.0masl), as part of complying with Rule 3 of the Waitaki Catchment Water Allocation Regional Plan (WAP).

Table 2.9: Characteristics of Lake Pukaki

Lake area (km^2)	178.70
Normal operational maximum level (m)	532.5
Normal operational minimum level (m)	518.20
Consented minimum level (m)	518.00
Maximum storage (million m^3)	2425.44
Minimum storage (million m^3) - at consented minimum level	0.00
Maximum contingent storage (million m^3) – when complying with the WAP	748.74

Table 2.10: Lake Pukaki Level-Area-Storage rating

Level (m)	Area (km²)	Storage (Mm³)
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	2425.44
534.00	181.83	2696.42
536.00	184.94	3063.18
538.00	187.98	3436.10

Table 2.11: Lake Pukaki Level-Area-Storage rating for Contingent Storage

Level (m)	Area (km²)	Storage (Mm³)
513.00	144.94	0
514.00	146.89	145.92
515.00	148.81	293.77
516.00	150.72	443.53
517.00	152.60	595.20
518.00	154.47	748.74

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 rather than Control Gates.

Table 2.12 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, with key values listed in Table 2.13.

Table 2.12: Characteristics of Lake Ohau

Lake area (km²)	61.20
Normal operational maximum level (m)	520.25
Normal operational minimum level (m)	519.75
Consented minimum level (m)	519.45

Table 2.13: Lake Ohau Level-Area-Storage rating

Level (m)	Area (km²)	Storage (Mm³)
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), 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). 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 2.14 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 portion of Lake Te Anau has vertical walls. 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, with key values listed in Table 2.15.

Table 2.14: Characteristics of Lake Te Anau

Lake area (km^2)	352.00
Maximum operating level (m)	202.70
Minimum operating level (m)	201.50
Absolute minimum (m)	200.86

Table 2.15: Lake Te Anau Level-Area-Storage rating

Level (m)	Area (km^2)	Storage (Mm^3)
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 3 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 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).

As with Lake Te Anau, Lake Manapouri has a complicated system governing the control levels. 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). 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 2.16 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, with key values listed in Table 2.17.

Table 2.16: Characteristics of Lake Manapouri

Lake area (km^2)	141.00
Maximum operating level (m)	178.60
Minimum operating level (m)	176.80
Absolute minimum level (m)	175.86

Table 2.17: Lake Manapouri Level-Area-Storage rating

Level (m)	Area (km^2)	Storage (Mm^3)
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. The maximum control level is 346m. This can, however, be exceeded under the Flood Management Plan.

Table 2.18 shows the characteristics of Lake Hawea, including the levels and lake area. The associated storage volumes are listed in the hydrological constraints dataset. A polynominal lake level–lake area rating was used to calculate the lake storage volumes, with key values listed in Table 2.19.

Table 2.18: Characteristics of Lake Hawea

Lake area (km²)	141.7
Maximum operating level (m)	346.0
Minimum operating level (m)	338.0

Table 2.19: Lake Hawea Level-Area-Storage rating

Level (m)	Area (km²)	Storage (Mm³)
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

Level (m)	Area (km²)	Storage (Mm³)
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 800m³/s except when flood emergency conditions prevail. Contact Energy treat the 'normal operating range' of Lake Wanaka as 276.35m to 278.00m (Table 2.20).

Table 2.20: '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 0m³. At the 'minimum operating level' there is still estimated to be 183.35 million m³ of storage.

Table 2.21 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, with key values listed in Table 2.22.

Table 2.21: Characteristics of Lake Wanaka

Lake area (km²)	193.00
Maximum 'operating level' (m)	278.00
Minimum 'operating level' (m)	276.35

Table 2.22: 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

Level (m)	Area (km²)	Storage (Mm³)
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 usable storage. These levels are adopted here as the minimum and maximum 'operating levels' for consistency with information from Contact Energy.

Table 2.23 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, with key values listed in

Table 2.24.

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 2.23: Characteristics of Lake Wakatipu

Lake area (km²)	293.00
Maximum 'operating' level (m)	310.80
Minimum 'operating level' (m)	309.60

Table 2.24: 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 elements 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 separated 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).

With permission from Meridian Energy Ltd, Mercury Ltd, and Contact Energy Ltd spill data has been retrieved from the Power Archive held by Opus. The spill volumes for Lake Tekapo and Lake Waikaremoana have been received from Genesis Energy Ltd.

Weekly spill volumes from 1 Jan 1980 to 31 Dec 2016 are included as part of this interim HMD update. 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' for the period of missing record.

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 unknown and therefore some discretion should be used.

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 Waikaremoana River at U/S Mangaone flow records can be used to determine the spill flows from Lake Kaiwawa and Lake Whakamarino. Waikaretaheke River at Piripaua is a sum of the spill flow from both Lake Kaitawa and Lake Whakamarino. Any flows above $2m^3/s$ at the Waikaremoana River at U/S Mangaone flow site is spill from Lake Kaitawa, while anything below $2m^3/s$ therefore is natural flow. Any flows above $2m^3/s$ at Waikaretaheke River at Piripaua are also spill flows which can be for either regulatory or operational reasons.

This spill data, provided by Genesis, is the best data available at this time. The quality of this data is unknown and therefore some discretion should be used. 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; Clyde; 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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