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Hydrological Modelling Dataset

Report 2: Flow Series Description and Methodology

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Contact Details

Dr Jack McConchie

WSP
L9 Majestic Centre
100 Willis Street
Wellington 6011
+64 4 471 7000

Jack.McConchie@wsp.com

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Prepared by

Lizzie Fox & Courtenay Bremner

Reviewed by

Deborah Maxwell

Approved for release by

Dr Jack McConchie

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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 information 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 second component of the HMD, the flow datasets.

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1 Introduction

This Hydrological Modelling Dataset (HMD) full update was requested by the Electricity Authority and includes data to 31 December 2020.

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 2020.

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 several 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 several 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 2020 for the 10 largest hydro lakes in NZ

- Spill volume:

Daily and weekly spill flow data for 25 sites in New Zealand including the 10 largest hydro-lakes and each of the structures downstream. Daily spill flow is now the primary timestep resolution for this dataset, to align with the other data. The 2020 update is the last update to include weekly spill flow.

The weekly 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. Daily spill data is from 24:00 to 24:00 filed at the end of the day, identical to the daily actual and natural flow datasets.

The lake storage, spill volumes, infrastructure attributes, and hydrological attributes datasets were produced for the first time in 2015. Daily spill volumes were produced for the first time in 2020.

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
- King Country Energy
- Meridian Energy Ltd
- Mighty River Power Ltd
- Pioneer Generation
- Trustpower

The HMD also relies heavily on data supplied by the National Institute of Water and Atmospheric Research (NIWA) from the Water Resources Archive (and funded by PGSF). Flow series from several rivers form a fundamental component of the datasets discussed. Their use in this report is consistent with the purpose for which Government funding is provided for their collection.

Additional river flow series were provided by Hawkes Bay Regional Council and Environment Canterbury Regional Council. Their assistance with this project is gratefully acknowledged.

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

All flow data are recorded at daily intervals from 00:00-24:00 and recorded at the 24:00 time step. This is standard hydrological practice for daily data as it represents the mean for the day.

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 affected 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 for 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 datasets is 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, Opus International Consultants Ltd, and currently, WSP.

With the break-up of the Electricity Corporation of New Zealand into several separate companies the 'Power Archive' was also partitioned. While the majority of the original 'Power Archive' is still maintained by WSP, several 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 WSP 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. If 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' code 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' indicates 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)
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 construction summary

The HMD data record for any flow series is often a composite record derived using different methods for different periods, as illustrated in Table 1-2 (North Island) and Table 1-3 (South Island).

Table 1-3 (South Island) lists the source of the record for each flow site and period. The quality code for each piece of the composite record is listed along with the definition of the quality code (Table 1-1). Small gaps and their associated quality code are not listed in the table; it provides the overarching quality for most of the data within each dataset. Manufactured (W) denotes the record is manufactured by WSP and Manufactured (RA) denotes the record has been manufactured by the recording authority.

Where records are not available or a scheme component was not commissioned for the early part of the period, such as the Ahuriri River at Benmore prior to 1949, synthetic flows are often used based on correlation with another flow record. This procedure can ensure that statistics, including the mean and standard deviation, of the simulated flows are as accurate as possible. However, the record has the unavoidable feature that the high and low flows in the simulated flow follow those of the flow site to which they are correlated. This can result in more extreme events in the overall generation system than would have occurred. Alternatively, it may result in a slightly compressed record with fewer extremes. As most of the simulated flows are relatively small, this is unlikely to have a major effect except when there is a focus on a specific flow event.

Table 1-2: Quality of HMD flow datasets for North Island flow sites.

Flow Site	Period	Quality Code	Code Definition
Arapuni tributaries	01/01/32 - 31/12/20	301	Synthetic – Simple Arithmetic
Karapiro tributaries	01/01/32 - 06/07/47	320	Synthetic – Manufactured (W)
	07/07/47 - 31/12/20	301	Synthetic – Simple Arithmetic
Tokaanu Linear	01/01/32 - 31/12/20	320	Synthetic – Manufactured (W)
Tokaanu TPD	01/01/32 - 31/12/20	320	Synthetic – Manufactured (W)
Taupo Linear	01/01/32 - 31/12/20	320	Synthetic – Manufactured (W)
Taupo TPD	01/01/32 - 31/12/20	320	Synthetic – Manufactured (W)
Taupo Natural	01/01/32 - 31/12/20	320	Synthetic – Manufactured (W)
Taupo Infrastructure	01/01/32 - 31/12/20	320	Synthetic – Manufactured (W)
Taupo Operational	01/01/32 - 31/12/92	310	Synthetic - Correlation
	01/01/93 - 31/12/20	320	Synthetic – Manufactured (W)
Rangipo Linear	01/01/32 - 31/12/20	320	Synthetic – Manufactured (W)
Rangipo TPD	01/01/32 - 31/12/20	320	Synthetic – Manufactured (W)
Waikaremoana	01/01/32 - 31/12/20	325	Synthetic – Manufactured (RA)
Matahina	01/01/32 - 31/12/66	350	Synthetic - Unknown
	01/01/67 - 31/12/20	325	Synthetic – Manufactured (RA)
Wheao	01/01/32 - 01/01/99	310	Synthetic - Correlation
	02/01/99 - 31/12/20	325	Synthetic – Manufactured (RA)
Mangahao	01/01/32 - 06/10/97	350	Synthetic - Unknown
	07/10/97 - 31/12/20	325	Synthetic – Manufactured (RA)
Patea	01/01/32 - 01/01/99	310	Synthetic - Correlation
	02/01/99 - 31/12/20	325	Synthetic – Manufactured (RA)
Kaimai	01/01/32 - 10/07/93	310	Synthetic - Correlation
	11/07/93 - 31/12/20	325	Synthetic – Manufactured (RA)
Ngaruroro at Whanawhana	01/01/32 - 31/08/60	310	Synthetic - Correlation
	01/09/60 - 31/12/20	200	Actual
Ngaruroro at Kuripapango	01/01/32 - 19/09/63	310	Synthetic - Correlation
	20/09/63 - 31/12/20	200	Actual
Ngaruroro at Chesterhope	01/01/32 - 25/11/76	310	Synthetic - Correlation
	25/11/76 - 31/12/20	200	Actual
Mohaka at Raupunga	01/01/32 - 28/02/57	310	Synthetic - Correlation
	01/03/57 - 31/12/20	200	Actual

Table 1-3: Quality of HMD datasets for South Island flow sites.

Flow Site	Period	Quality Code	Code Definition
Waitaki tributaries	01/01/32 - 31/12/20	301	Synthetic – Simple Arithmetic
Benmore	01/01/32 - 31/12/20	320	Synthetic – Manufactured (W)
Benmore t_p	01/01/32 - 31/12/20	320	Synthetic – Manufactured (W)
OhauRes	01/01/32 - 31/12/20	320	Synthetic – Manufactured (W)
Ohau	01/01/32 - 31/12/20	320	Synthetic – Manufactured (W)
Pukaki	01/01/32 - 31/12/20	320	Synthetic – Manufactured (W)

Natural Pukaki	01/01/32 - 31/12/20	301	Synthetic – Simple Arithmetic
Tekapo	01/01/32 - 31/12/20	320	Synthetic – Manufactured (W)
Natural Tekapo	01/01/32 - 31/12/20	320	Synthetic – Manufactured (W)
Manapouri	01/01/32 - 07/09/69	320	Synthetic – Manufactured (W)
(with Mararoa)	08/09/69 - 31/12/20	301	Synthetic – Simple Arithmetic
Manapouri	01/01/32 - 01/05/32	320	Synthetic – Manufactured (W)
(without Mararoa)	02/05/62 - 31/12/20	301	Synthetic – Simple Arithmetic
Manapouri (water right reduction)	01/01/32 - 31/12/20	320	Synthetic – Manufactured (W)
Te Anau	01/01/32 - 31/12/20	320	Synthetic – Manufactured (W)
Monowai Inflow	01/01/32 - 30/04/77	310	Synthetic - Correlation
	01/05/77 - 31/12/20	320	Synthetic – Manufactured (W)
Roxburgh tributaries	01/01/32 - 31/12/20	301	Synthetic – Simple Arithmetic
Wanaka	01/01/32 - 31/12/20	200	Actual
Hawea	01/01/32 - 31/12/20	320	Synthetic – Manufactured (W)
Cobb	01/01/32 - 21/11/45	310	Synthetic - Correlation
	22/11/45 - 31/12/20	325	Synthetic – Manufactured (RA)
Coleridge	01/01/32 - 31/12/50	320	Synthetic – Manufactured (W)
	01/01/51 - 31/12/20	325	Synthetic – Manufactured (RA)
Highbank	01/01/32 - 30/04/51	350	Synthetic - Unknown
	01/05/51 - 30/04/98	325	Synthetic – Manufactured (RA)
	01/05/98 - 31/05/02	350	Synthetic - Unknown
	01/06/02 - 31/12/20	325	Synthetic – Manufactured (RA)
Waipori	01/01/32 - 31/12/87	350	Synthetic - Unknown
	01/01/88 - 16/09/97	310	Synthetic - Correlation
	17/09/97 - 30/06/10	200	Actual
	01/07/10 - 18/05/12	310	Synthetic - Correlation
	19/05/12 - 31/12/20	200	Actual
Grey + Taramakau (No Taipo) (CLOSED)	01/01/32 - 31/12/15	320	Synthetic – Manufactured (W)
Grey + Taramakau (No Taipo)	01/01/32 - 31/12/20	320	Synthetic – Manufactured (W)
Clarence at Jollies	01/01/32 - 27/03/34	340	Synthetic – Replicated Data
	28/03/34 - 31/12/59	310	Synthetic - Correlation
	01/01/60 - 31/12/20	200	Actual
Waiau at Glenhope	01/01/32 - 31/01/74	310	Synthetic - Correlation
	01/02/74 - 05/07/99	200	Actual
	06/07/99 - 26/09/03	310	Synthetic - Correlation
	27/09/03 - 17/07/08	200	Actual
	18/07/08 - 31/12/20	310	Synthetic - Correlation
Waiau at Marble Point	01/01/32 - 06/10/67	310	Synthetic - Correlation
	06/10/67 - 31/12/20	200	Actual
Wairau at Dip Flat	01/01/32 - 29/03/34	340	Synthetic – Replicated Data
	30/03/34 - 31/05/51	310	Synthetic - Correlation
	01/06/51 - 31/12/20	200	Actual
Hurunui at Mandamus	01/01/32 - 29/03/34	340	Synthetic – Replicated Data

	30/03/34 - 25/10/56	310	Synthetic - Correlation
	26/10/56 - 31/12/20	200	Actual
Hurunui at SH1 Bridge	01/01/32 - 13/12/74	310	Synthetic - Correlation
	13/12/74 - 18/06/99	200	Actual
	18/06/99 - 20/08/00	310	Synthetic - Correlation
	21/08/00 - 31/12/20	200	Actual
Lake Onslow	01/01/32 - 31/12/20	310	Synthetic - Correlation

1.5 Summary and description of flow sites

A summary of each of the HMD flow sites is listed in Table 1-4 for the North Island and Table 1-5 for the South Island.

Table 1-4: North Island flow dataset names and mean values derived for this HMD update (2021).

Flow	Model flow name	Flow site number	Description	Mean flow (m ³ /s)	Type
Arapuni Tribs	Arapuni	92724 (1)	Waikato tributary flow between Taupo and Arapuni PS	81.49	A
Karapiro Tribs	Karapiro	92714 (1)	Waikato tributary flow between Taupo and Karapiro PS	91.08	A
Tokaanu	TokaanuTPD	92790 (3)	Non-linear correlations of Taupo natural inflows used to create Tokaanu inflow	52.39	A
	Toka_Linear	22790 (3)	Linear correlations of Taupo natural inflows used to create Tokaanu inflow	53.24	A
Taupo	TaupoTPD	92790 (1)	Sub catchment inflows non-linear functions of Taupo inflows to create Taupo inflows including TPD diversions using 1995-2004 consent conditions	155.45	A
	Taupo_Linear	22790 (1)	Linear correlations of Taupo natural inflows used to create Taupo inflows including TPD diversions	154.13	A
	Taupo_Actual	42790 (1)	Rating distribution correlates TPD flow and Taupo inflow, based on the 1993 to 2005 operating regime to create Taupo inflows including TPD diversions. Reflects the current operating regime.	139.91	A
	Taupo_infra	72790(1)	Non-linear correlations of Taupo natural inflows used to create Taupo Inflows including TPD Diversions using consent conditions as active from 2004 to present	148.60	A
Natural Taupo	Nat_Taupo	62790(1)	Natural Taupo Inflow	125.55	N
Rangipo	RangipoTPD	92790 (2)	Sub-catchment inflows are based on non-linear function of Taupo inflows to create Rangipo inflows. Incorporates latest water right discharges.	34.62	A

	Rangi_linear	22790 (2)	Linear correlations of Taupo natural inflows used	28.8	A
Waikaremoana	Waikaremoana	3650 (1)	Waikaremoana Inflows	17.64	N+A
Matahina	Matahina	93254 (1)	Matahina Inflows	64.40	A
Wheao	Wheao	15462(1)	Wheao/Flaxy Power Station outflow	12.82	A
Mangahao	Mangahao	97502(1)	Local inflows	8.67	A
Patea	Patea	34300(1)	Patea Power Station outflow	19.55	A
Kaimai	Wairoa	14130(1)	Kaimai outflows at Ruahihi	11.86	A
Ngaruroro	Whanawhana	123103 (1)	Ngaruroro River flow at Ngaruroro at Whanawhana recorder	34.97	N+A
	Kuripapango	123104 (1)	Ngaruroro River flow at Ngaruroro at Kuripapango recorder	17.69	N+A
	Chesterhope	123150 (1)	Ngaruroro River flow at Ngaruroro at Chesterhope recorder	43.64	N+A
Mohaka	Raupunga	121801 (1)	Mohaka River flow at Mohaka at Raupunga	78.91	N+A

"N" denotes a natural flow, uncontrolled flow

"A" denotes an actual flow

"N+A" denotes a flow that is both actual and natural

(*) Denotes item number of historic Tideda file, data is now stored in Hilltop Manager and uses the primary number

Table 1-5: South Island flow dataset names and mean values derived for this HMD update (2021).

Flow	Model flow name	Site number	Description	Mean flow (m ³ /s)	Type
Waitaki P.S. Tribs	Waitaki	98714 (2)	Waitaki tributary flows between Lakes Pukaki & Tekapo and Waitaki Lake relative to Waitaki Power Station	149.60	A
Benmore	Benmore	98614 (4)	Waitaki tributary flow between Lakes Pukaki & Tekapo and Benmore (Separate Tekapo simulation) and includes Tekapo spill	132.77	A
	Ben_tp	98615 (2)	Waitaki tributary flow between Lakes Pukaki & Tekapo and Benmore (Combined lakes Tekapo - Pukaki simulation) which is Ohau inflow plus the scaled Ahuriri River flow	123.41	A
Ohau (separate Tekapo model)	OhauRes	98614 (6)	Ohau A only, residual flows of 12m ³ /s May to Oct and 8m ³ /s Nov to Apr	70.39	A
	Ohau	98614 (3)	Ohau B and C only. Assumes all Ohau inflow flows into Ohau B and C	80.29	N+A
Pukaki	Pukaki	98614 (2)	Pukaki inflows including Tekapo outflows, removing the Tekapo B station discharges from 1977 to avoid duplication	195.59	A
Natural Pukaki	Nat_Puk	98770 (1)	Natural Lake Pukaki inflow	126.52	N
Tekapo	Tekapo	98614 (1)	Separate Tekapo simulation	69.13	A
Natural Tekapo	Nat_Tek	98770 (2)	Natural Lake Tekapo Inflow	83.62	N+A
Manapouri	Manawmara	99551 (1)	Manapouri local inflows allowing for Mararoa dirty water spill	137.07	A

	Manapouri	99550 (1)	Manapouri local inflows with no Mararoa input	122.14	N
	Manareduced	99552 (1)	Manapouri local inflows allowing for Mararoa dirty water spill, 12, 14 and 16m ³ /s min flow from MLC, flushing and recreational releases from MCL	125.78	A
Te Anau	Teanaui	9570 (1)	Te Anau Inflows	284.48	N+A
Monowai	Mono_Inflow	199540 (1)	Monowai Power Station inflows based on the measured downstream flow sites of the Monowai River	12.96	N+A
Roxburgh	Roxburgh	99110 (1)	Roxburgh tributary flows - but excluding Hawea outflows	446.64	A
Wanaka	Wanaka	9154 (1)	Wanaka outflows	197.63	N+A
Hawea	Hawea	9170 (1)	Hawea inflows	64.47	N+A
Cobb	Cobb	97904 (2)	Cobb inflows	5.38	N+A
Coleridge	Coleridge	97904 (1)	Coleridge inflows	24.77	A
Highbank	Highbank	7968(1)	Highbank Power Station outflow	13.48	A
Waipori	Waipori	174395(1)	Waipori Power Station outflow	7.41	A
Grey+ Taramakau-Taipo	Grey_tara_closed	77106(1)	Grey River at Dobson including Taramakau but not Taipo. This site is now closed because the Taipo and Taramakau datasets are unavailable, requiring a new methodology for calculation	436.32	A
Grey+ Taramakau-Taipo	Grey_tara	77106(2)	Grey River at Dobson including Taramakau but not Taipo. Calculated by correlating the Dobson flow record with the derived Grey River+Taramakau-Taipo dataset series where they overlap, because of both the Taramakau and Taipo flow sets are now unavailable	431.80	A
Waiau	Clarence	162105 (1)	Waiau River flow at Clarence at Jollies recorder	14.41	N+A
	Glenhope	164604 (1)	Waiau River flow at Waiau at Glenhope recorder	33.63	N+A
	Marble Point	164602 (1)	Waiau River flow at Waiau at Marble Point recorder	93.78	N+A
Wairau	Dip Flat	160114 (1)	Wairau River flow at Wairau at Dip Flat recorder	26.48	N+A
Hurunui	Mandamus	165104 (1)	Hurunui River flow at Hurunui at Mandamus recorder	51.12	N+A
	SH 1 Bridge	165101 (1)	Hurunui River flow at SH1 Bridge	66.21	N+A
Lake Onslow	Onslow	175237 (1)	Lake Onslow Inflows simulated from a correlation based on catchment area from Waipori	5.40	N+A

"N" denotes a natural flow, uncontrolled flow

"A" denotes an actual flow

"N+A" denotes a flow that is both actual and natural

(*) Denotes item number of historic Tideda file, data is now stored in Hilltop Manager and uses the primary number

2 Actual Flows

2.1 North Island

2.1.1 *Waikato (Arapuni and Karapiro)*

For the HMD flow series, tributary flow is calculated at Arapuni and Karapiro. Flow records at Karapiro do not begin until 1947 and the earlier record has been simulated from the Arapuni record.

Tributary flows at Arapuni are calculated simply by subtracting the Taupo outflows from the outflows at Arapuni. Karapiro tributary flows are calculated similarly for the period of actual record (7 July 1947 – 1 July 1997) and are simulated from Arapuni tributary flows, scaled up by 20%, for the period before 1947 (Halliburton, December 1993).

2.1.2 *Tokaanu, Taupo and Rangipo*

The Tongariro Power Development (TPD) simulation has undergone revision over time, to incorporate changing hydrological infrastructure, constraints and optimisation of flow regimes. This has resulted in the creation of three individual modelling datasets that represent the Taupo Inflows, along with two datasets of inflows at Rangipo and Tokaanu.

In the 2018 full update, two additional Taupo Inflow series were further created, to model the Natural Taupo Inflows and the Taupo Inflow regime; incorporating only the consents active from 2004.

Each of these datasets are described in detail below that are created as part of the HMD update.

2.1.2.1 *Site 22790*

Site 22790 was the original Taupo, Tokaanu and Rangipo inflow simulation at each of these locations in the TPD scheme. It uses four input sites: Taupo Inflows (2790), Waihohonu at Desert Road, Wairehu Canal at Gauging Bridge and Lake Moawhango Inflows. Using linear calculations and correlations, the inflow series are derived, with the original minimum flow conditions and infrastructure as at 1993 included. The script used is TAUPO.SIM. The datasets are back calculated to 1932.

This site was superseded in 1996 by site 92790, following the conclusions from the 1992 Waikato River consent hearing. These datasets are still included in the HMD update for historical reference.

In 2020, the historic Tideda script was updated into Hilltop Manager software. This software has increased accuracy as it 'stores' the entire number, rather than rounding to a whole number. This will be the procedure for future updates, and has resulted in differences due to rounding for the 2020 update.

2.1.2.2 *Site 92790*

Following an extensive revision of the TPD simulation (Henderson, 1996) to incorporate minimum flow rules at Te Maire on the Whanganui River, Turangi and Poutu Intake on the Tongariro River, and different rules about spill at Rangipo Intake and flows at Waikato Falls, site 92790 was created for Taupo, Tokaanu and Rangipo Inflows. Several logical errors in the previous simulation (pre-1996) were also corrected. Consequences of the changes introduced were:

- 2.5m³/s increase in Taupo inflows;
- 6.2m³/s increase in Rangipo flows;
- 2.1m³/s decrease in Tokaanu flows; and
- 1.2m³/s increase in Western Diversion flows.

Using the derived Taupo Natural Inflow series from the Total Inflow series, this dataset simulates the flow series at various rivers, canals and reservoirs within the TPD scheme using non-linear correlations, incorporating the change in infrastructure constraints to model the inflows back to 1932. It uses two scripts; TAUPOFUN.SIM and TAUPOTPD.SIM which detail the inputs and various

rules of the simulation. This simulation therefore supersedes site 22790 as it optimises the flow regime, and uses the consents following the 1992 Waikato consent hearing.

From 1 December 2004 further consent conditions were introduced, which required increased releases to the Whanganui River from the Western Diversions, and therefore a reduction in flows diverted to Lake Taupo. Following a detailed review (Opus, 2016), a new simulation and site was created using the operational Taupo Inflow series. This dataset, site 72790, more accurately incorporates the observed changes of Tongariro Power Development Foreign Inflows (TPD Inflows) into Lake Taupo than site 92790. Therefore, site 92790 is superseded by site 72790 to represent the present-day infrastructure back calculated to 1932.

Site 92790 for Tokaanu, and Rangipo Inflows, were not reviewed at this time, and therefore remain as the primary inflow series for these sites, superseding site 22790 for their respective inflows.

2.1.2.3 Site 42790

In 2015 a new dataset was created to represent the 'actual' Taupo Inflows, as used by Mercury. This dataset is part of the Power Archive and is derived from the relationship between measured Lake Level and measured Total Outflow from Lake Taupo. It is derived from Taupo Total Inflow, site 2790, and is used as part of site 22790.

This operational inflow dataset more accurately represents the true TPD operating regime, as it captures the changing infrastructure through time; from June 1932 to September 1969 the flows mirror the Taupo natural inflows, before the addition of TPD Foreign inflows into the lake. This naturalised dataset (1932-1969) was correlated with the TPD Foreign Inflows operating regime from 1993 to 2005, to allow for back calculation to 1932. It therefore reflects the changes to minimum flow regimes in the wider catchment through time and should be used to represent the 'actual' inflows into Lake Taupo.

This dataset is provided from the Power Archive for each update, therefore any changes between updates reflects data corrections, rating changes, or other forms of modifications following review and auditing of the dataset.

2.1.2.4 Site 62790

In 2018 a new dataset was requested by the Electricity Authority to show the naturalised inflow series into Lake Taupo. This dataset had been used as an input site for 92790 and 42790 historically, but had not been included as part of the HMD update as an individual site.

This dataset is derived from a correlation of the recorded Lake Level and Net Outflow from Lake Taupo, which requires the Tongariro Power Development (TPD) Foreign Inflows dataset from Genesis. Any changes to the TPD dataset will impact the naturalised series, and therefore sites 92790 and 42790.

This dataset is the simulated natural inflow into Lake Taupo if there was no TPD scheme, and therefore has less flow than the 'actual' total inflow for Lake Taupo.

2.1.2.5 Site 72790

Following a detailed review of the Taupo Inflow simulation regime of site 92790 and site 42790 (Opus, 2016) a new Taupo Inflow dataset was created, with the purpose of being included in future HMD updates. Site 72790, the Taupo Inflow Infrastructure dataset, was created to represent the current operating regime back calculated to 1932.

The site is derived by correlating the TPD Inflows with the actual total inflow series (i.e., site 42790) from 2004-2020, to back calculate the TPD Inflows to 1932. This means the most recent consent conditions are used. This extended TPD inflow series is then added to the naturalised Taupo inflow series, i.e., site 62790. The result is a Taupo Inflow series which represents the theoretical inflow into Lake Taupo, if the 2004 consents were active from 1932.

This site supersedes site 92790 for Taupo Inflows in representing the current infrastructure back to 1932, as it uses the most up to date information.

2.1.2.6 Process to calculate TPD flow sites

A detailed summary of how each of the sites used to create the above sites is described below.

1 Net Taupo outflows

Subtract recorded diversion flows (Wairehu Canal and Moawhango Tunnel) from Taupo outflows to give net Taupo outflows. Genesis provides a dataset called 'TPD Foreign Inflows' which includes all flows that have been diverted into Lake Taupo.

2 Taupo total inflows (site 2790)

Uses total inflows data from the Power Archive. This is calculated on a monthly basis as part of the Mercury Energy monthly Power Archive update. It is used to create site 42790, which is identical where actual measurements are, with data prior to TPD Foreign Inflows simulated with the natural inflow record back to 1932.

3 Taupo natural inflows (site 62790)

Uses the net Taupo outflows and Lake Level data from Lake Taupo, along with TPD Foreign Inflows dataset provided by Genesis.

4 Outline of TAUPOFUN.SIM

Uses full record of Taupo Natural Inflows (62790) as input to TAUPOFUN.SIM.

Apply non-linear transformations to Taupo natural inflows, to simulate flows at the following locations in the scheme:

- Western Diversion with no minimum flow rules
- Tongariro at Turangi natural flows
- Natural inflow to Lake Rotoaira
- Natural inflows to the lower Tongariro above Turangi and downstream of Poutu Dam and Poutu Intake.
- Natural inflows to the middle Tongariro between Rangipo Dam and Poutu Intake
- Natural flows in the Tongariro River at Rangipo Dam
- Natural flows in the Waihohonu Stream at Waihohonu Tunnel
- Natural inflows to Lake Moawhango
- Flows in the Wahianoa Aqueduct at Mangaio Tunnel
- Natural flows in the Whanganui River at Te Maire

Write results to an intermediate Tideda file.

5 Merge modelled natural flows

Overwrite modelled flows in the intermediate file at all locations listed above (except Wahianoa Aqueduct) with simulated natural flows based on recorded data.

6 Outline of TAUPOTPD.SIM

- Model effect of Te Maire minimum flows to reduce Western Diversion flows
- Add Waihohonu tunnel flows to Rangipo and subtract from mid Tongariro
- Add Wahianoa flow to Moawhango inflow
- Model Lake Moawhango operation and Moawhango Tunnel flows
- Determine Poutu spill required
- Determine Rangipo spill required
- Determine if Rangipo (and Moawhango) should be shut down because flows too high

- Calculate total available flow at Rangipo
- Calculate total available flow at Tokaanu
- Calculate Taupo inflow including diversion flows for full record

More detail is given for the various components below:

Net Taupo outflows – Because the next step uses an algorithm based on the idea of natural river flow recessions, the net outflows are needed rather than the total outflows as recorded. Taupo net outflows are those that would have occurred if no additional water was diverted into the catchment, i.e., the TPD Foreign Inflows subtracted from the Total Outflow of Lake Taupo.

Taupo natural inflows – A lake inflow algorithm that takes lake levels and net outflows and calculates inflows that have realistic recession shapes is also used, so that the resulting inflow time series is useable for simulation of natural flows at other locations. Previous inflows have had erratic behaviour especially at low flows, caused by fluctuations in recorded levels because of atmospheric effects on the lake, and fluctuations in outflows caused by generation requirements. Taupo natural inflows are those, which would have flowed into Lake Taupo anyway; so, no adjustment is necessary here. It is the Taupo Natural inflow record, which is used to extend shorter low flow records, and to simulate the flows that would have occurred at various flow sites, had they been as they are today back in 1932.

Flow transformations – Data recorded in the rivers and diversions of the scheme have been used to model natural flows at various locations since 1960 when data recording began. The result of this work, done mostly as part of resource consent studies and for the Whanganui Minimum Flows Appeal, has been used to derive a set of non-linear transformations. These quasi-quadratic functions allow the transformation of Taupo natural inflows into time series that preserve the flow distribution of the modelled series. This means that not only the mean but also higher order moments of the modelled series are preserved. Linear regressions would only preserve the mean if the relationship modelled is in fact linear. These considerations are particularly important when using the modelled series to simulate rules that involve minimum flows and flood flows.

Merge modelled natural flows – Application of the flow transformations is for the full length of record (1932 to present). A better estimate of natural flow at each location since approximately 1960 can be gained by using the model data that was used to derive the transformations. This has the advantage that during extreme events flows at all flow sites will be independently measured, rather than a scaled version of Taupo inflows. The true magnitude of extremes will thus be better estimated.

Western Diversion – The flow in the Western Diversion, as if it were run with no releases down the Whakapapa River, is modelled by transforming Taupo natural inflows. The result is a ‘natural’ looking hydrograph with a maximum value of 41.6m³/s. Flow in the Whanganui River at Te Maire is also modelled by transforming Taupo natural inflows. The Western Diversion flow is subtracted from the Te Maire flow, and the result tested against the new minimum flow rule (29m³/s from 1 December to 31 May each year, no rule at other times). If the rule is violated, water is released from the Western Diversion to meet it. This means, at times, there is no diversion of water.

Eastern Diversion and Tongariro – Inflows to various parts of the Tongariro River are determined. Flows above Rangipo are derived by subtracting these modelled flows from modelled flows at Turangi. Waihothonu River diversion flows and Moawhango inflows (including Wahianoa Aqueduct flows) are calculated and the “total flows at Rangipo (RangipoTPD)” are then determined by adding these to the Tongariro flow at Rangipo.

The contribution to flow at Tokaanu from the Tongariro River is calculated by adding Rangipo inflows to the Tongariro inflows between Rangipo and Poutu and subtracting Poutu spill (Moawhango Tunnel contribution is included at each step so that the tunnel capacities are properly dealt with).

Rotoaira local inflows are calculated and the minimum release (0.6m³/s) down Poutu Stream is subtracted. Finally, the Western Diversion flows and Poutu Tunnel flows are added to the Rotoaira local inflows and water diverted from the Tongariro River to establish the “total flow available at Tokaanu Power Station (TokaanuTPD)”.

Taupo Inflow – The “total inflow to Lake Taupo (TaupoTPD)”, incorporating diverted water from the TPD scheme. This is achieved by a lake inflow algorithm that uses Lake Level and Total Outflow from Lake Taupo, and is part of the Power Archive, calculated on a monthly basis for Mercury.

Taupo Actual Inflow (site 42790) – TPD flows were correlated with the calculated Taupo inflows for the period between 1993 and 2005. This resulted in a very strong correlation ($r^2 = 0.9911$). A distribution rating was used to extend the TPD flows back to 1932 using Taupo inflows. This synthetic TPD flow dataset was added to Taupo natural inflows to represent inflow including TPD back to 1932, i.e., the infrastructure at that time as if it existed from 1932. From 1 September 1992 to present actual Taupo inflows are used as this is when the “normal operating regime” of TPD begins.

The dataset should be used if water balance modelling is done. However, the TaupoTPD dataset (site 72790) is more similar to inflow datasets because optimal water table (within consents etc.) is included in the dataset.

2.1.3 *Waikaremoana*

Inflow records for Lake Waikaremoana go back to 1929. Inflows to individual scheme components were not originally available and so inflows were based on flows at Tuai Power Station. These include leakage but do not include water spilt at the Kaitawa gates which is not recaptured at the Whakamarino canal intake. Waikaremoana inflow data has been revised and improved in the past and the methods that were used to recalculate the inflows can be found in Works Consultancy Services Ltd “Hydrological Data Reference Manual; Lake Waikaremoana Inflow Data 1929 to 1995” (Greer et al., 1996).

However, from June 2001 onwards, Genesis Energy has calculated Waikaremoana inflows directly. Data supplied for HMD updates suffer from negative inflows because of leakage associated with Lake Waikaremoana. At the request of the Electricity Authority, negative inflows supplied were set to zero for the purposes of water balance modelling, though the data from Genesis Energy still contains the negative values. Genesis Energy are working on ways to solve this negative inflow issue.

2.1.4 *Matahina*

Flows are available for the Matahina Power Station since its commissioning in 1967. From 1948 to 1967 flows are simulated from the Rangitaiki River at Te Teko and prior to 1948 from Lake Taupo outflow.

Feedback highlighted that the synthetic data prior to 1948 appears to be inconsistent with the later record, i.e., the standard deviation for this period is 50% lower. This difference is most likely caused by the inability of the simulation process to accurately model flood events. The resulting apparent reduction in the magnitude of floods has a significant influence on the standard deviation. Since the energy generation potential of the river is most strongly related to the ‘average’ flow conditions, this inconsistency for a period of the data record is not regarded as significant.

This flow site is not recalculated back to 1932 as part of a full HMD update. The data are supplied by the parent company and is simply appended to the previous dataset. Matahina outflows – 93254 (1) is one of these flow sites.

2.1.5 *Wheao/Flaxy*

Historically, data for the Wheao Power Station outflows was supplied by Trustpower from 1999 to 2016. It was therefore necessary to extend this record back from 1999 to 1932. Data was available from Rangitaiki at Murupara from 1948 to 2008. For this update, only new data from 2018 to the end of 2020 was supplied.

To create a synthetic record for Rangitaiki at Murupara from 1948 back to 1932, a flow distribution rating (obtained via analysis of Taupo Natural Outflows and Rangitaiki at Murupara) was applied to Taupo Natural Outflow.

To reduce the Rangitaiki at Murupara flow range to resemble Wheao Power Station flows, another flow distribution rating was derived using Rangitaiki at Murupara and Wheao Power Station. This flow distribution was then applied to actual and synthetic Rangitaiki at Murupara data to derive synthetic Wheao flow data.

This flow site is not recalculated back to 1932 as part of a full HMD update. The data is supplied by Trustpower and simply appended to the previous dataset.

Care was taken to maintain the water balance of the power station output. Table 2-1 details the mean flows for the synthetic and actual data.

Table 2-1: The mean actual and synthetic outflow data for the Wheao power station.

Record	Record Length	Mean Flow (m ³ /s)
Actual Wheao Power Station	1999-2007	12.5
Synthetic Wheao Power Station*	1999-2007	12.3
Actual and Synthetic Wheao Power Station	1932-2020	12.8

*Prior to superimposing the actual Wheao record over the HMD series

2.1.6 Mangahao

Because of the limited data available for the Mangahao Power Scheme a simulated No.2 reservoir inflow record has been produced (Freestone & Maslin, October 1991). The No.2 inflow record represents 97% of the total scheme inflow; the remaining 3% comes from the Arapeti (No.3) catchment. The synthetic record is based on a series of different methods each considered appropriate for a period of the scheme's history. A trend is apparent when the cumulative deviation from the mean is examined for the synthetic record. However, this has been compared with the Manawatu River record and is considered to be real.

Machine flows were calculated using a modified cumecs to megawatt ratio based on analysis of individual machine loads (G1, G2 and G3) and accuasonic data over the 1996 period. Revised cumecs/MW ratios of 0.431 (G1 Francis) and 0.503 (G2 and G3 Peltons) were also calculated.

In 2008, the Mangahao dataset was reviewed, including both the historic synthetic data, and the actual data over the more recent period of record. This review suggests that a reasonable level of confidence can be placed in the modelling of synthetic data; although a mean of 8m³/s may be too low when compared to more recent measured data. However, the measured data covers a very short period giving a comparable record of only three years. Therefore, even though the 2018 data suggests that 12m³/s may be the correct mean flow for the scheme, it would not be advisable to change data based on such a short flow record.

As a result of the review, although there is some uncertainty relating to the data from the Mangahao scheme, however it is believed to provide a good indication of the overall energy situation.

Mangahao data from 8 October 1997 to 31 December 2020 are actual data. Inflow data are based on spill from the No. 2 dam and machine generation, i.e., outflows. King Country Energy have noted however, that the communications cable downstream of No2 Dam has had issues in the past, with spill data from 28-April-2013 until 2017 deemed unreliable and has been replaced with spill data from No1 Dam. This should be quite accurate as the tipgate position is used to calculate spill flows. It does not include spill flows less than 1m³/s. For both the 2018 and 2020 HMD updates, No. 2 dam spill and machine generation data was provided and combined to represent the inflows.

This flow site is not recalculated back to 1932 as part of a full HMD update. The data is supplied by KCE/Trustpower and is simply appended to the previous dataset.

2.1.7 Patea

The synthetic outflow data for Patea Power Station was created in 2007. Data for this power station was supplied by Trustpower from 1999 to 2007. It was therefore necessary to extend this record back from 1999 to 1932. To do this, data from Patea River at Mangamingi and McColls were used.

The Patea at Mangamingi record begins in April 1975 and ends in April 1984. The Patea at McColls record runs from November 1986 to July 1995. Data from these two flow sites were combined to give a non-continuous record from 1975 to 1995.

To create a synthetic record for Patea from 1975 back to 1932, a flow distribution rating (obtained via analysis of Taupo Natural inflow and combined Patea) was applied to Taupo Natural inflow.

To reduce the combined Patea flow range to resemble Patea Power Station flows another flow distribution rating was derived using combined Patea and Patea Power Station. This flow distribution was then applied to actual and synthetic Patea data to derive synthetic Patea flow data.

This flow site is not recalculated back to 1932 as part of a full HMD update. The data is supplied by Trustpower and is simply appended to the previous dataset.

Care was taken to maintain the water balance in the Patea River. Table 2-2 details the mean flows during the record for the synthetic and actual data.

Table 2-2: The mean outflow for Patea Power Station and Patea River.

Record	Record Length	Mean Flow (m ³ /s)
Patea at Mangamingi	1975-1984	24.2
Patea at McColls	1986-1995	28.1
Patea Power Station	1999-2007	18.5
Synthetic Patea Power Station Data*	1999-2007	16.9
Actual and synthetic Patea Power Station	1932-2020	19.6

*Prior to superimposing the actual Patea record over the HMD series

2.1.8 Kaimai

The SPECTRA dataset for the Kaimai scheme was created in 2007 using flow site 14132 Wairoa at Power Station. The flow site begins July 1993 and finishes in February 2007. The Wairoa at Power Station record was extended back from 1993 to 1932. Synthetic data was created by analysing simulated natural Taupo inflow and Wairoa at Power station and applying the distribution rating to the simulated natural inflow record at Lake Taupo. Actual data is now recorded at the generation outflow form Ruahihi powerhouse representing the Kaimai outflow.

Actual data and synthetic data were combined to provide a flow record for Wairoa at Power Station from 1932 to 2020.

This flow site is not recalculated back to 1932 as part of a full HMD update. The data is supplied by Trustpower and is simply appended to the previous dataset.

Table 2-3 shows the mean flow for each record for synthetic and actual data. Comparisons were made to ensure a similar water balance was maintained for Kaimai outflows at Ruahihi when creating synthetic data.

Table 2-3: The mean outflow for Kaimai at Ruahihi.

Record	Record Length	Mean Flow (m ³ /s)
Wairoa at Power Station	1993-2007	12.0
Synthetic Wairoa at Power Station*	1993-2007	12.1
Actual and synthetic Kaimai at Ruahihi	1932-2020	11.9

*Prior to superimposing the actual Wairoa record over the HMD series

2.1.9 Ngaruroro River, Hawkes Bay

In a previous Opus report, Additional SPECTRA Investigations (Payne, 2005), five possible hydro-power schemes were identified along the Ngaruroro River. The HMD series have been developed at three of the flow recording sites to represent flows at these schemes; Ngaruroro at Whanawhana, Ngaruroro at Kuripapango and Ngaruroro at Chesterhope Bridge.

2.1.9.1 Ngaruroro at Whanawhana

The longest flow record in the vicinity of the Ngaruroro River is the Ngaruroro at Fernhill data. This record extends back to 1953. Unfortunately, no gaugings were available at this flow site between 1974 and 2005 resulting in unrealistic flows. Consequently, data from this period could not be used. The Ngaruroro at Whanawhana record, which extends back to 1960, is used instead. The Ngaruroro at Whanawhana recorder was correlated with the longer Lake Waikaremoana inflow record to extend the HMD series back to 1932.

The best correlation was obtained through a distribution rating of the Lake Waikaremoana record (1960-2001). The distribution of flow in the resulting dataset is similar to the actual distribution of flow, therefore the Ngaruroro at Whanawhana record is used from 1960 to present.

Inflow to Lake Waikaremoana is calculated from lake level and outflow data. The resulting Ngaruroro at Whanawhana rated record between 1932 and 1960 has some lake level characteristics, including a greater number of flood events. Care was taken to maintain the water balance in the river.

Table 2.4: Ngaruroro at Whanawhana mean flow

Record	Record Length	Mean Flow (m ³ /s)
Ngaruroro at Whanawhana	1960-2001	35.2
Rated Ngaruroro at Whanawhana*	1960-2001	34.9
Rated Ngaruroro at Whanawhana	1932-2020	35.0

*Prior to superimposing the actual Whanawhana record over the HMD series

2.1.9.2 Ngaruroro at Kuripapango

The Ngaruroro at Kuripapango record begins in 1963. This record was extended back to 1932 through a distribution correlation with the extended Ngaruroro at Whanawhana record. The distribution rating compared flow data over the period 1963 to 2006. Actual data from the Ngaruroro at Kuripapango record is appended to the rated data. Care was taken to maintain the water balance in the river. Table 2.5 details the mean flows during the record correlation phases.

Table 2.5: Ngaruroro at Kuripapango mean flow

Record	Record Length	Mean Flow (m ³ /s)
Ngaruroro at Kuripapango	1963-2005	17.2
Rated Ngaruroro at Kuripapango*	1963-2005	17.1
Rated Ngaruroro at Kuripapango	1932-2020	17.7

*Prior to superimposing the actual Ngaruroro at Kuripapango record over the HMD series

2.1.9.3 Ngaruroro at Chesterhope Bridge

The Ngaruroro at Chesterhope Bridge record begins in 1976. This record was extended back to 1932 through a distribution correlation with the extended Ngaruroro at Whanawhana record. The distribution rating compared flow data over the period 1976 to 2006. Actual data from the Ngaruroro at Chesterhope Bridge record is applied to the rated data. Gaps in the Chesterhope Bridge record are filled from the synthetic data.

The data showed very low summer flows in 1948 and 1954. The rest of the synthetic data is reasonable. Care was taken to maintain the water balance in the river. Table 2.6 details the mean flows during the record correlation periods.

Table 2.6: Ngaruroro at Chesterhope Bridge mean flow

RECORD	RECORD LENGTH	MEAN FLOW (M ³ /S)
Ngaruroro at Chesterhope Bridge	1976-2005	41.8
Rated Ngaruroro at Chesterhope Br*	1976-2005	41.3
Rated Ngaruroro at Chesterhope Br	1932-2020	43.6

*Prior to superimposing the actual Ngaruroro at Chesterhope Bridge record over the HMD series

details the mean flows during the record correlation phases. Mean flow has remained consistent.

Table 2.4: Ngaruroro at Whanawhana mean flow

Record	Record Length	Mean Flow (m ³ /s)
Ngaruroro at Whanawhana	1960-2001	35.2
Rated Ngaruroro at Whanawhana*	1960-2001	34.9
Rated Ngaruroro at Whanawhana	1932-2020	35.0

*Prior to superimposing the actual Whanawhana record over the HMD series

2.1.9.4 Ngaruroro at Kuripapango

The Ngaruroro at Kuripapango record begins in 1963. This record was extended back to 1932 through a distribution correlation with the extended Ngaruroro at Whanawhana record. The distribution rating compared flow data over the period 1963 to 2006. Actual data from the Ngaruroro at Kuripapango record is appended to the rated data. Care was taken to maintain the water balance in the river. Table 2.5 details the mean flows during the record correlation phases.

Table 2.5: Ngaruroro at Kuripapango mean flow

Record	Record Length	Mean Flow (m ³ /s)
Ngaruroro at Kuripapango	1963-2005	17.2
Rated Ngaruroro at Kuripapango*	1963-2005	17.1
Rated Ngaruroro at Kuripapango	1932-2020	17.7

*Prior to superimposing the actual Ngaruroro at Kuripapango record over the HMD series

2.1.9.5 Ngaruroro at Chesterhope Bridge

The Ngaruroro at Chesterhope Bridge record begins in 1976. This record was extended back to 1932 through a distribution correlation with the extended Ngaruroro at Whanawhana record. The distribution rating compared flow data over the period 1976 to 2006. Actual data from the Ngaruroro at Chesterhope Bridge record is applied to the rated data. Gaps in the Chesterhope Bridge record are filled from the synthetic data.

The data showed very low summer flows in 1948 and 1954. The rest of the synthetic data is reasonable. Care was taken to maintain the water balance in the river. Table 2.6 details the mean flows during the record correlation periods.

Table 2.6: Ngaruroro at Chesterhope Bridge mean flow

RECORD	RECORD LENGTH	MEAN FLOW (M ³ /S)
Ngaruroro at Chesterhope Bridge	1976-2005	41.8
Rated Ngaruroro at Chesterhope Br*	1976-2005	41.3
Rated Ngaruroro at Chesterhope Br	1932-2020	43.6

*Prior to superimposing the actual Ngaruroro at Chesterhope Bridge record over the HMD series

2.1.10 Mohaka River, Hawke's Bay

The longest flow record on the Mohaka River is the Mohaka at Raupunga recorder. This record extends back to 1957. The Mohaka at Raupunga record was correlated with the Lake Waikaremoana inflow record to extend the HMD series back to 1932.

On 6 January 1985 a large landslide occurred upstream of the Raupunga gauge. This suppressed flow at the gauge significantly for approximately 10 hours and impacted on flows for approximately three days. The low stage value resulting from the landslide was removed from the data for the distribution analysis to provide a normal distribution of data.

The best correlation was obtained through a distribution rating of the Lake Waikaremoana inflow record comparing flow data over the period 1957-2001. The distribution of flow in the resulting dataset is like actual flow at the high end of the spectrum. Flows at the low end of the spectrum are slightly lower than the actual record.

Inflow to Lake Waikaremoana is calculated from lake level and outflow data. The resulting Mohaka at Raupunga rated record between 1932 and 1957 has some lake level characteristics, including a greater number of oscillations. Rated low flows are slightly lower and more common than in the actual record as the lake inflow regularly drops to zero.

The Mohaka at Raupunga record (including the suppressed flow values in 1985) is used from 1957 to present. Gaps in the record were filled from correlation with the Ngaruroro at Whanawhana record.

Care was taken to maintain the water balance in the river. Table 2-7 details the mean flows during the record correlation periods.

Table 2-7: The mean flow for Mohaka at Ruapunga.

Record	Record Length	Mean Flow (m ³ /s)
Mohaka at Raupunga*	1957-2001	79.5
Rated Mohaka at Raupunga**	1957-2001	78.7
Rated Mohaka at Raupunga	1932-2017	78.9

*Without low flows triggered by the landslide.

**Prior to superimposing the actual Mohaka at Raupunga record over the HMD series.

2.2 South Island

2.2.1 Waitaki

For the HMD modelling, the flows in the Waitaki River are considered in two components, inflow to Lakes Pukaki and Tekapo; and tributary inflows below the lakes at Benmore and Waitaki Power Stations.

2.2.1.1 Pukaki and Tekapo inflows

Two options are modelled:

- Pukaki Inflows are the calculated inflows from a lake level and outflow algorithm combined with the Tekapo Outflows from the Tekapo Canal, and therefore could be used for power generation downstream. The natural Pukaki inflows are simulated from subtracting the actual Tekapo discharge into Lake Pukaki to simulate the inflows prior to the current infrastructure.
- Tekapo Inflows are the calculated inflows from Lake Tekapo into the Tekapo Canal; they are therefore constrained by the maximum capacity of the Canal (130m³/s) and the minimum release flows that Genesis must comply with as part of the agreement with Meridian. These flows therefore look more like outflows, but represent the inflows that are available for power generation at Tekapo A and Tekapo B power stations.

2.2.1.2 Ohau Inflows

Ohau A is affected by residual flows in the Upper Ohau River. Therefore, two simulations are run to represent available inflows from Ohau for generation:

- Ohau – Ohau B & C only, no loss of water. This is the total inflow into Lake Ohau that is available; and
- OhauRes – Residual flows diverted to the Upper Ohau River of 12m³/s (Nov to Apr) and 8m³/s (May to Oct). This results in less available inflows available for use.

2.2.1.3 Benmore Tributary

This includes Ahuriri, Ohau, and tributaries between Tekapo, Pukaki, and Ohau outfalls. Prior to 1949 the Ahuriri River was not measured, so it is simulated from Ohau inflows. After 1964 the flow gauging site was inundated by Lake Benmore, so a flow site further up the river at South Diadem is used, with a scaling factor to account for additional inflows. Small tributary flows in the areas between the major lakes and Benmore are accounted for by adding 33% to the Ahuriri flow.

There are two flows sets for Benmore tributaries:

- Benmore is based on the separate Tekapo simulation and includes Tekapo spill.
- Benmore_tp is based on the combined lakes Tekapo-Pukaki simulation and is simply Ohau inflow plus Ahuriri scaled up by 1.33.

2.2.1.4 Waitaki Tributary

A separate tributary flow has also been produced for Waitaki power station (Halliburton, December 1993). Previously, Waitaki and Aviemore tributaries were scaled from Benmore. Waitaki tributary equals total Waitaki flow minus the outflow from Lakes Tekapo and Pukaki. Prior to 22 August 1977 this was calculated from the total discharge from each lake, whereas after that date it is calculated from total Pukaki discharge minus Tekapo spill only.

There are several gaps in the early Pukaki outflow record. A simulation has been incorporated into the updating routines, which fills these gaps with synthetic data based on Tekapo outflows.

Feedback from the draft SPECTRA 2007 report highlighted poor Waitaki flow data when compared to Benmore. Measurement inaccuracies produce negative flows when compared to Benmore power station tributaries. However, the effect tributaries have on lake levels is complicated and require assumptions that do not necessarily work well for long term records. Meridian suggests that work on these inaccuracies should be addressed on a project by project basis for shorter data sets.

2.2.2 Manapouri

The HMD Manapouri data is intended to be used as local inflows, whereas Lake Te Anau has a controllable outflow. Hence two separate files are required for the HMD. Inflows and outflows for Lake Te Anau are available from 1926 and for Lake Manapouri from May 1932. The local catchment, or tributary, contribution to Manapouri inflow is determined by subtracting the Te Anau outflows

from the total Manapouri inflows. For the period before 30 April 1932 when the record at Manapouri began, the local inflows are simulated from Te Anau outflow.

For the purposes of the HMD modelling, a record of Manapouri local inflows is required upon which future predictions of inflows can be based. To achieve this, records are synthesised which either include or exclude the Mararoa River for the entire record. The Mararoa has been included in the Power Archive inflows since the commissioning of the Manapouri Power Station in August 1969. Outflow was first measured downstream of the Mararoa confluence (with power station flows added) (Duffy et al., 1993).

Prior to the availability of actual Mararoa River records, and for filling gaps, synthetic flows are simulated from Te Anau outflows. The equations used were derived by Robertson et al. (1989) and later confirmed by Maslin et al. (1993).

Several options are available for the Manapouri flows:

- With Mararoa diversion (*site 99551*). Note that when Mararoa flows are above 40m³/s, the Mararoa is spilled. This only approximates the actual operation of the Mararoa control structure. Also, when Mararoa water is being spilled, it is not possible to avoid some clean water spill from Lake Manapouri. This is hypothetical actual flow.
- Without Mararoa (*site 99550*), which represents the view of a possible extreme outcome of water rights application. This is a hypothetical natural flow, not an actual flow series.
- With the minimum flow regime implemented and Mararoa dirty water spill (*site 99552*). This is hypothetical actual flow.

The minimum flow regime was introduced to the model. Previously, the minimum flow was assumed to be a constant 15m³/s throughout the year, although to date, there has not been a regular minimum flow except for a nominal minor flow through the fish pass. The 15m³/s figure was hypothetical only.

2.2.3 Monowai

Inflows previously existed from 1960 to 1999, however this methodology has since been updated as described below.

From January 1932 to April 1977 the data for Monowai Inflow was derived from correlating nearby river data. A linear regression with Te Anau and Manapouri did not provide a suitable correlation. Therefore, a flow distribution rating was applied to extend the previous Monowai record. A rating was derived from the 'Monowai Riddell - Opus' and Lake Te Anau inflow data, and then applied to the Te Anau inflow data. This resulted in some differences for peak flow events in regard to timing, however, the two systems tracked each other well and flows were similar.

From the 2015 update, this dataset is calculated using the Opus inflow regime and was recalculated back to May 1977. This is because of changes in NIWA ratings for input flow sites. This caused some differences in data which are further explained in Report 2a. Table 2-8 details the mean flows for the records. The same approach is continued by WSP.

Table 2-8: The mean flow for Monowai.

Record	Record Length	Mean Flow (m ³ /s)
Riddell Inflow 1986 Report	1960 - 1985	12.3
Riddell - Opus Inflow	1960 - 1999	12.9
Monowai Rated Inflow	1960 - 1999	13.1
Monowai Rated Inflow & Riddell - Opus Inflows	1927 - 2006	13.0
Monowai Rated Inflow & Riddell - WSP Inflows	1932 - 2020	13.0

2.2.4 Clutha

2.2.4.1 HMD flow records

Hawea – Inflows to Lake Hawea are read directly from the Power Archive and daily averaged.

Wanaka - Outflows from Lake Wanaka are read directly from the Power Archive and daily averaged.

Roxburgh - Roxburgh inflows are read directly from the Power Archive and Hawea outflows are subtracted to provide a local inflow dataset. This is daily averaged.

2.2.5 Cobb

Prior to 1945, inflow to the Cobb reservoir was not recorded. Initially, inflows were simulated back to 1932 using a correlation with Lake Coleridge inflows. The 1993 SPECTRA Update used an improved method, utilising a correlation with Lake Rotoroa outflows since 1934 (Palmer, 1992 and Maslin et al., 1993). The first few years of inflows, however, are still based on Coleridge inflows.

This correlation was reassessed for the 1996 SPECTRA Update and an unsatisfactory r^2 value was obtained. After discussion with Lennie Palmer, ECNZ Generation (1996), it was decided to continue with the value (0.224) in the existing PSIM. This is based on the correlation of mean inflows at Coleridge and Cobb. From March 1934 to November 1945 the inflows are based on a correlation with Gowan at Rotoroa. From November 1945 to present, the inflows are calculated by Trustpower from actual outflow records with an allowance for change in lake storage.

This flow site is not recalculated back to 1932 as part of a full HMD update. The data is supplied by Trustpower and is simply appended to the previous dataset.

2.2.6 Coleridge

The inflows into Lake Coleridge are from the local catchment together with diversions from the Wilberforce, Harper, and Acheron Rivers. Diversions from the Harper and Wilberforce rivers cease during floods when the diversion bunds are washed away. During the floods the only inflows are therefore from the local catchment and the Acheron Diversion. There are also turbidity constraints imposed on lake inflows.

The inflows are calculated using the equation:

$$\text{Inflow} = \text{outflow} \pm \text{change in storage}$$

where outflows include machine discharge, spill flow and the Oakden diversion outflow. The change in storage volume is calculated from measured lake levels (at the Power Station intake) and a lake level-volume relationship.

Lake Coleridge inflows prior to 1951 were initially synthesised from the Harper River flows but these were generally of poor quality. In late 1993, some historic weekly power station reports from 1928 to 1951 were located in the station archives. From these several data items were loaded to computer which enabled the calculation of actual lake inflows. The resulting inflow record was a substantial improvement over the previously synthesised flows. This record replaced the synthetic record in the 1994 SPECTRA update.

When the Coleridge “Hydrological Data Reference Manual” (Greer, 1994) was compiled, the inflows were again scrutinised. A further period of record, recalculated with the pre-1951 data, was replaced on the archive. This involved only a relatively minor change to the way in which the inflows were calculated from April 1951 to September 1963. It did not significantly affect the mean flow. Note that the efficiency of the diversion works varies and this may affect flow trends. Data from 26 January 1998 to 31 December 2002 is synthetic record.

This flow site is not recalculated back to 1932 as part of a full HMD update. The data is supplied by Trustpower and is simply appended to the previous dataset.

2.2.7 Highbank

The ECNZ Highbank Power Station record begins in May 1951 and ends in May 1998. In June 2002, Trustpower began recording flow which continues.

In a 1990 Works Consultancy Services report, “Extended Flow Study – Mohaka, Mangahao, Grey, Arnold and Highbank”, a synthetic Highbank dataset was created from 1931 to 1951. Some gaps exist in the dataset so as part of this report synthetic data were created to fill these gaps. The same PSIM that was used in the 1990 report was used in this study.

The PSIM uses variations in Lake Coleridge inflows to produce synthetic data. Actual Highbank data (ECNZ and Trustpower) and synthetic data were combined to provide a HMD flow record for Highbank Power Station.

This flow site is not recalculated back to 1932 as part of a full HMD update. The data is supplied by Trustpower and is simply appended to the previous dataset.

Table 2-9 shows the mean flow for each record for the synthetic and actual data. Comparisons were made to ensure a similar water balance was maintained for the Highbank Power Station when creating synthetic data. The differences in mean flow may be partly caused by different companies running the power station in different ways.

Table 2-9: The mean outflows for Highbank Power Station.

Record	Record Length	Mean Flow (m ³ /s)
Highbank actual (ECNZ)	1951-1988	
Highbank actual (Trustpower)	2002-2008	
Synthetic Highbank	1931-2007	
Actual and synthetic Highbank	1932-2017	

2.2.8 Waipori

The HMD series for Waipori scheme was created in 2007. Waipori at Berwick and Waipori at Below No 4 Power Station data were correlated and compared with long term flow stations in the vicinity of the Waipori catchment. The long term flow stations used in the comparisons were Lake Wanaka, Lake Te Anau, Lake Manapouri, Lake Wakatipu, and Lake Roxburgh inflow, Clutha at Alexandra Bridge, and Clutha at Balclutha.

None of the seven lakes/flow sites had a comparable flow relationship with Waipori at Below No 4 Power Station (74395) or Waipori at Berwick (74321). The Waipori catchment contains a large lake, Lake Mahinerangi, and four power stations along the Waipori River. Lake Mahinerangi has a large storage capacity and therefore can absorb any flood events. Any flow released from the lake passes through four power stations. This means that the flows in this catchment are totally controlled and behave differently from the natural flow occurrences in adjoining catchments. Figure 2-1 shows a flow hydrograph for Waipori at Below No 4 power station.

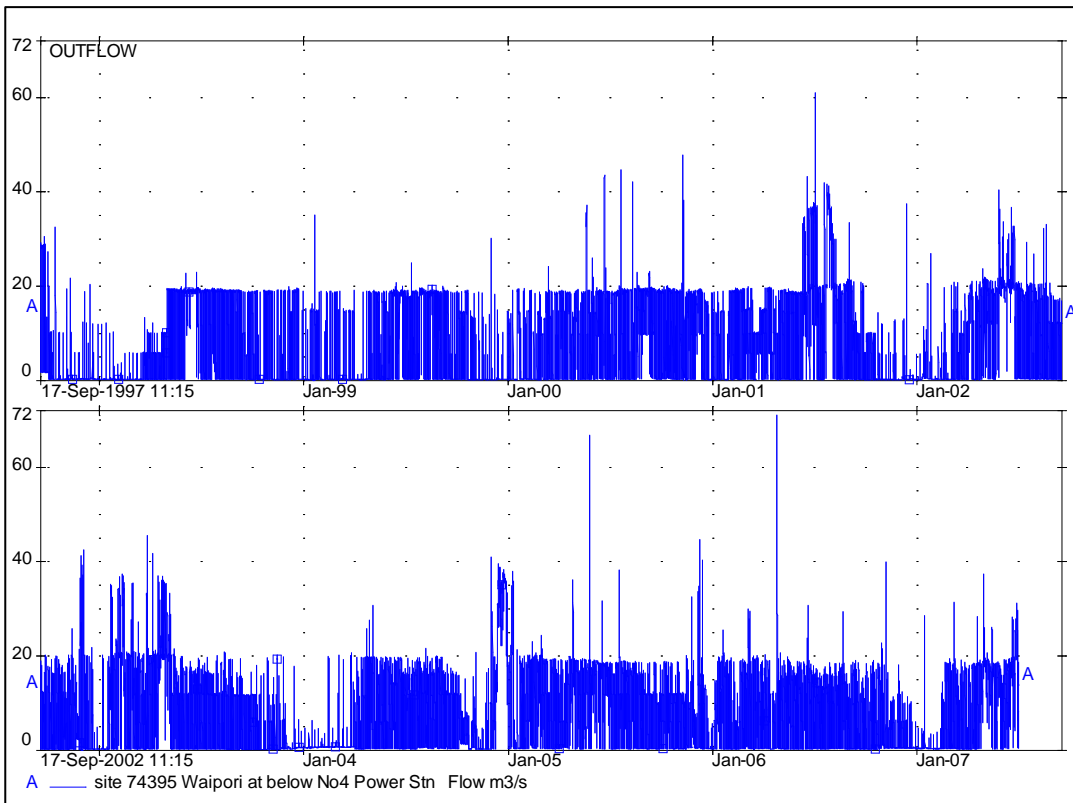


Figure 2-1: The flow at Waipori for Below No 4 Power Station.

Figure 2-2 highlights how the Waipori catchment does not reflect the behaviour of the surrounding catchments; Figure 2-2 shows Waipori at Below No 4 power station versus Lake Wanaka outflow. Waipori mainly has the profile associated with turbine discharge and occasional spill discharges. The spill discharges do not coincide with high flow events at Wakatipu. This comparison was found to be consistent across all flow sites when compared with Waipori.

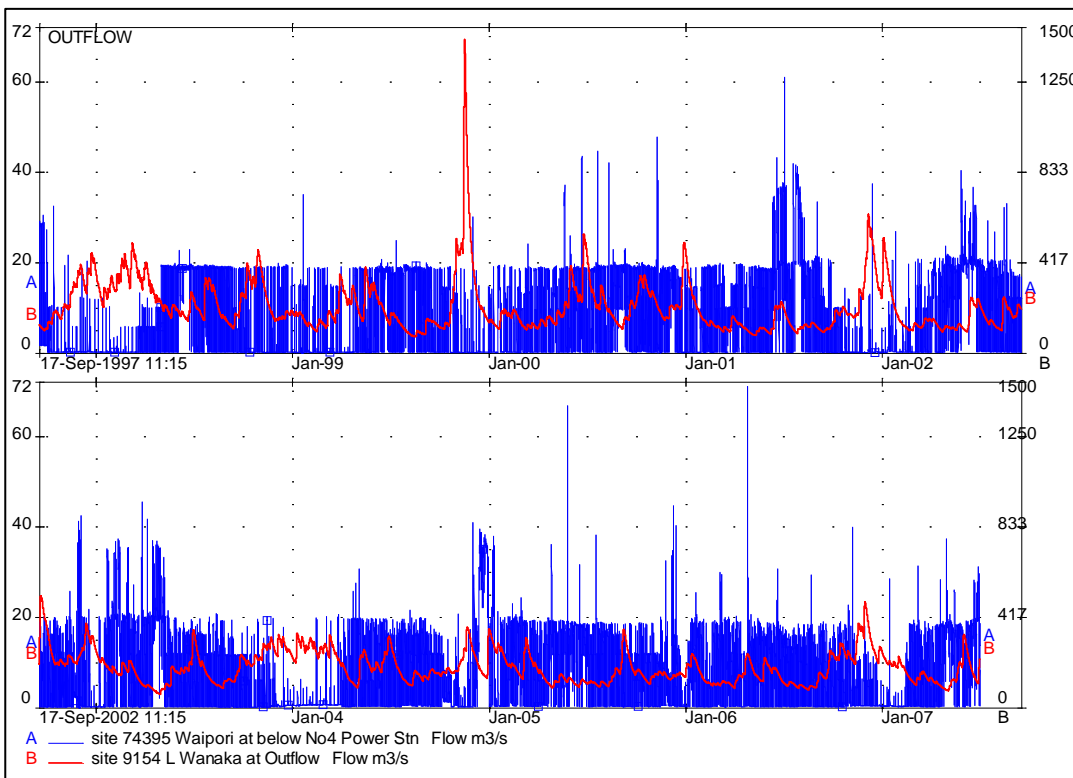


Figure 2-2: The flow at Waipori Below No 4 Power Station compared with Lake Wanaka outflow.

To create a synthetic flow dataset for this catchment an analysis was conducted for Waipori at Berwick and Waipori at Below No 4. The resultant flow distribution rating was then applied to Waipori at Berwick to reduce flows to that of Waipori at Below No 4.

Synthetic Waipori at Below No 4 data was combined with actual Waipori at Below No 4 Power Station to give a record from 1988 to 2007. The ratios from the “Trends in Flow Data report (1993)” were used and annual data series that had means that reflected the historic means were used to infill the dataset from 1932 to 1988.

Actual data and synthetic data were combined to provide a flow record for Waipori at Below No 4 Power Station from 1932 to 2007.

Waipori at Below No 4 Power Station data was not available for the period 1-Jul-2010 to 19-May-2012 from Trustpower. A correlation with Waipori at Berwick was undertaken and inserted into the missing period.

This flow site is not recalculated back to 1932 as part of a full HMD update. The data is supplied by Trustpower and is simply appended to the previous dataset.

Table 2-10 shows the mean flow for each record for synthetic and actual data. Comparisons were made to ensure a similar water balance was maintained for Waipori at Below No 4 Power Station when creating synthetic data.

Table 2-10: The mean flows for Waipori at Below No 4 Power Station.

Record	Record Length	Mean Flow (m ³ /s)
Waipori at Below No 4 Power Station	1997-2007	7.6
Waipori at Berwick	1988-2007	10.9
Synthetic Waipori at Below No 4 PS*	1998-2007	7.1
Actual and synthetic Waipori at Below No 4 Power Station	1932-2020	7.4

*Prior to superimposing the actual Waipori record over the HMD series

2.2.9 Lake Onslow

From 2020, the EA requested a dataset of inflows to Lake Onslow to be included in the HMD update. There is considerable interest in this site for future pumped storage generation.

Inflows to Lake Onslow have not been recorded; therefore it was decided to use the outflows from the lake as a surrogate. There is an active flow station downstream of Lake Onslow: Teviot at Bridge Huts Road. However, as this contains a ‘baseflow’ it was deemed to be likely overrepresenting the likely inflows into Lake Onslow. Therefore, the simulated inflows into the nearby Waipori power scheme was deemed more appropriate. This was scaled by catchment area to synthesize the inflows into Lake Onslow.

The catchment area at the Lake Onslow dam has a catchment area of 126km² compared to a catchment area of 317km² for the Waipori Station, resulting in a scaling factor of 0.728.

2.2.10 Grey River

A flow record for the Grey River at Dobson is available from July 1968 until present. An earlier record is synthesised from the Buller River at Berlins from 1952 to 1968, and from Lake Te Anau inflow prior to 1952. Lake Te Anau gave the best results of the few records available for the early period from 1930 (Freestone & Mills, June 1990).

The dataset used in the HMD is the flow in the Grey River at Dobson, including water diverted from the Taramakau River. This is derived from another dataset that also includes water diverted from the Taipo River. This is because the Taramakau at Greenstone Bridge recorder includes Taipo River flow,

as it is downstream of the Taipo confluence. The calculation of the combined Grey+Taramakau-Taipo data is outlined below.

To determine the flows available for diversion into the Grey some assumptions must be made, as there are currently no firm scheme details. These are summarised as follows:

- Residual flows are required in the Taramakau and Taipo Rivers of 15m³/s and 5m³/s, respectively;
- Maximum canal flow is 230m³/s (twice the mean);
- Shut down of diversion structure intake during floods is not considered; and
- Utilisation of the water available for diversion is assumed to be 70%.

Based on these assumptions the diverted water is calculated. This is then added to the Grey at Dobson record. For the period before February 1979, when the Taramakau at Greenstone record begins, the total flow set is synthesised from the extended Grey record, based on the correlation between the two, from 1979 to the end of the Taramakau at Greenstone record in 2015.

The dataset only including Taramakau is then derived from the Grey+Taramakau-Taipo record by scaling down by 0.93, i.e., assuming that 7% of the total water is diverted from the Taipo River.

NIWA closed the Taramakau at Greenstone Bridge site at the end of 2015; and the Taipo at SH1 bridge site in June 2016. Both sites are now closed, as of 2017. From 2017 onwards a new Grey River dataset has been created, with the original dataset maintained and included in the HMD update; there are now two Grey River datasets: site 77106 (1) Grey_Closed and site 77106 (2) Grey. The latter is calculated to the present day.

The second Grey River dataset is correlated from the Grey River at Dobson flow site distribution and the combined Grey+Taramakau-Taipo flow distribution for the period where the records overlap; 1979 to 2015. This resulted in a very strong correlation ($r^2=0.99$). A synthesized total flow series is derived by applying a non-linear rating to the Grey River at Dobson dataset. This synthetic flow set has the same assumptions of diversion and base flows as the previously derived dataset.

Table 2-11 details the mean flows of the actual Grey River at Dobson record compared to the period of correlation and the final synthesized Grey+Taramakau-Taipo datasets.

Table 2-11: Mean flows for the Grey River.

Record	Record Length	Mean Flow (m ³ /s)
Grey River at Dobson	1979-2016	367.8
Grey+Taramakau-Taipo	1979-2016	448.4
Synthesized Grey+Taramakau-Taipo (original site)	1931-2016	436.3
Synthesized Grey+Taramakau-Taipo from Grey River (correlated site)	1931-2020	431.8

2.2.11 Waiau River, Canterbury

Four possible hydro-power scheme locations have been identified along the Waiau River. These are the Clarence to Waiau Diversion, Upper Waiau, Mid Waiau and Lower Waiau. The HMD records have been developed at three locations within the catchment; these are Clarence at Jollies (Clarence diversion), Waiau at Glenhope (Upper Waiau), and Waiau at Marble Point (Mid Waiau).

2.2.11.1 Clarence at Jollies

The longest flow record in the vicinity of the Waiau River is the Clarence at Jollies recorder. Data extends back to 1960. The Clarence at Jollies recorder was correlated with the longer Gowan at Lake Rotoroa flow record to extend the HMD dataset back to April 1934.

The best correlation was obtained through a flow distribution rating of the Gowan record (1934-1991). The distribution of flow in the resulting dataset is similar to the actual distribution of flow. However, the Gowan record is based on lake inflows so many flood peaks have been reduced. Actual data from the Clarence at Jollies record (1960-2006) replaces the rated data.

The first three years of record (1932-1934) were selected from average flows. The Works Consultancy Services Ltd produced a report in 1993 titled “Trends in Flow Data for Manapouri Local Inflows, Mangahao, Cobb, Coleridge Inflows and Waikato Tributary Flows”. Appendix III of the report specified ratios from flow sites throughout New Zealand of the mean annual inflow to the mean total record, since 1932. Ratios less than one indicated inflows to the site were less than average and hence a dryer year; ratios greater than one indicated inflows to the site were greater than average and hence a wetter year. The mean annual ratios at Lake Coleridge, which is the nearest flow site to the Waiau River, were 0.77, 0.65, and 1.05 during 1932, 1933, and 1934, respectively. 1932 and 1933 were therefore dryer years than average.

The ratios were then applied to the total mean flow of the rated Clarence at Jollies record. Mean annual flows were determined for the three years and compared to annual flows from the entire record. Flows from years that had similar mean annual flows were replicated in the earlier record. Flows from 1956 are repeated in 1932, flows from 1969 are repeated in 1933, and flows in the first three months of 1953 are repeated in 1934.

Care was taken to maintain the water balance in the river. Table 2-12 details the mean flows during the record correlation phases. This flow has remained constant.

Although the mean flows compare well there is less flood peak amplitude in the correlated record 1932 to 1960. However, the overall water balance is good.

Table 2-12: The mean flow at Clarence at Jollies.

Record	Record Length	Mean Flow (m ³ /s)
Clarence at Jollies	1960-1999	14.9
Rated Clarence at Jollies*	1960-1999	15.0
Rated Clarence at Jollies	1932-2020	14.4

*Prior to superimposing the actual Clarence at Jollies record over the HMD series

2.2.11.2 Waiau at Glenhope

The Waiau at Glenhope record begins in 1974. This record was extended back to 1932 through a distribution correlation with the extended Clarence at Jollies record. The distribution rating compared flow data over the period 1974 to 1999.

The Waiau at Glenhope flow site was not rated between 1999 and 2003 and is currently no longer rated (July 2008). The location is too dangerous to gauge at low flows in the jet-boat and too difficult to wade. To produce a flow series, a synthetic rating is produced using a distribution correlation with Marble Point.

There is less flood activity in the synthetic record (pre 1974) and this may, when combined with the low flow period in the 1930s, produce an overall slightly lower long-term mean flow (2.3m³/s (6%) lower).

Care was taken to maintain the water balance in the river. Table 2-13 details the mean flows during the record correlation phases. This flow has remained constant.

Table 2-13: The mean flow for Waiau at Glenhope.

Record	Record Length	Mean Flow (m ³ /s)
Waiau at Glenhope	1974-1999	35.8
Rated Waiau at Glenhope*	1974-1999	35.7
Rated Waiau at Glenhope	1932-2020	33.6

*Prior to superimposing the actual Waiau at Glenhope record over the HMD series

2.2.11.3 Waiau at Marble Point

The Waiau at Marble Point record begins in 1967. This record was extended back to 1932 through a distribution correlation with the extended Clarence at Jollies record. The distribution rating compared flow data over the period 1967 to 2002. Data from February 2003 at the Marble Point flow site is provisional and was therefore not used in the distribution rating. Actual data from the Waiau at Marble Point record (1967 – 2006) is applied to the rated data.

Care was taken to maintain the water balance in the river. Table 2-14 details the mean flows during the record correlation phases. This flow has remained constant. The slightly lower mean flow for the longer record (1932 to 2012) is because of a dry period in the 1930s, and the reduced flood activity in the synthetic record.

Table 2-14: The mean flow for Waiau at Marble Point.

Record	Record Length	Mean Flow (m ³ /s)
Waiau at Marble Point	1967-2002	98.7
Rated Waiau at Marble Point*	1967-2002	98.8
Rated Waiau at Marble Point	1932-2020	93.8

*Prior to superimposing the actual Waiau at Marble Point record over the HMD series

2.2.12 Wairau River, Marlborough

There are currently two small power stations located on the Branch River near the Wairau River. The proposed scheme is to extend this existing hydro-electric scheme. The Wairau at Dip Flat record is important for the extension of this scheme.

2.2.12.1 Wairau at Dip Flat

The longest flow record in the vicinity of the Wairau River is from the Wairau at Dip Flat recorder. This record extends back to 1951. The Wairau at Dip Flat recorder was correlated with the Gowan at Lake Rotoroa flow record to extend the HMD series back to April 1934.

The best correlation was obtained through a distribution rating of the Gowan record comparing flow data over the period 1934-1991. The distribution of flow in the resulting dataset is similar to the actual distribution of flow. Actual data from the Wairau at Dip Flat record (1951-2006) is used.

As with the Waiau extension, the first three years of record were selected from average flows from the Works Consultancy Services Ltd report titled “Trends in Flow Data for Manapouri Local Inflows, Mangahao, Cobb, Coleridge Inflows and Waikato Tributary Flows (1993)”. The mean annual inflow ratios (averaging ratios from Mangahao and Coleridge) were 0.805, 0.795, and 0.995 in 1932, 1933, and 1934 respectively. This period was dryer than average.

The ratios were applied to the total mean flow of the correlated Gowan record (1934-2006, including actual data from the Wairau at Dip Flat record from 1951). Mean annual flows were determined for the three years and compared to annual flows from the entire record. Flows from years that had similar mean annual flows were replicated in the earlier record. Flows from 1941 are replicated in 1932 and 1933 and flows in 1954 are replicated in the initial three months of 1934.

Gaps in the record were filled from correlation with the Wairau at Hells Gate record (1965-1975) and the Wairau at Tuamarina flow site (1989-1999) which was replaced with the Barnett's Bank recorder 390m upstream (1999-2006). Care was taken to maintain the water balance in the river. Table 2-15 details the mean flows during the record correlation phases.

Table 2-15: The mean flow for Wairau at Dip Flat.

Record	Record Length	Mean Flow (m ³ /s)
Wairau at Dip Flat	1951-1991	26.7
Rated Wairau at Dip Flat*	1951-1991	27.0
Rated Wairau at Dip Flat	1932-2020	26.5

*Prior to superimposing the actual Wairau at Dip Flat record over the HMD series

2.2.13 Hurunui River, Canterbury

There are two options for a proposed hydro-power scheme along the Hurunui River. The first is upstream of State Highway 1 Bridge near the mouth of the river; the second possible location is upstream of the Hurunui at Mandamus flow site.

2.2.13.1 Hurunui at Mandamus

The longest flow record on the Hurunui River is the Hurunui at Mandamus recorder. This record extends back to 1956. The Hurunui at Mandamus record was correlated with the longer Gowan at Lake Rotoroa flow record to extend the HMD series back to 1934.

The best correlation was obtained through a distribution rating of the Gowan record comparing flow data over the period 1934 to 1991. The distribution of flow in the resulting dataset is similar to the actual distribution of flow. However, the Gowan record is based on lake inflows so flood peaks are often smoothed. The Hurunui at Mandamus record is used from 1956 to present.

As with the Waiau extension, the first three years of record were selected from average flows from the Works Consultancy Services Ltd report titled "Trends in Flow Data for Manapouri Local Inflows, Mangahao, Cobb, Coleridge Inflows and Waikato Tributary Flows (1993)". The mean annual inflow ratios at Coleridge were 0.77 in 1932, 0.65 in 1933, and 1.05 in 1934.

The ratios are applied to the total mean flow of the correlated Gowan at Lake Rotoroa record (1934-2006, including actual Hurunui at Mandamus data from 1956). Mean annual flows were determined for the three years and compared to annual flows from the entire record. Flows from years that had similar mean annual flows were replicated in the earlier record. Flows from 1989 are replicated in 1932, flows from 1960 are replicated in 1933, and flows from 2003 are replicated in the initial three months of 1934. Care was taken to maintain the water balance in the river. Table 2-16 details the mean flows during the record correlation phases.

Table 2-16: The mean flow for Hurunui at Mandamus Bridge.

Record	Record Length	Mean Flow (m ³ /s)
Hurunui at Mandamus	1956-1991	51.2
Rated Hurunui at Mandamus*	1956-1991	52.1
Rated Hurunui at Mandamus	1932-2020	51.1

*Prior to superimposing the actual Hurunui at Mandamus Bridge record over the HMD series

2.2.13.2 Hurunui at SH1 Bridge

The most downstream flow site in the Hurunui catchment is the Hurunui at SH1 Bridge flow site. Flow data at this site exists from 1974 to 1999. Between June 1999 and July 2008 this site is used for flood warning only. It has now been reinstated and a fully rated flow site. The lower Hurunui River is

potentially the most useful for hydro-power development because of the greater catchment area and Pahau tributary.

The Hurunui at SH1 Bridge was extended back to 1932 through a distribution correlation with the extended Hurunui at Mandamus record. The distribution rating compared flow data over the period 1974 to 1999. Actual data from the Hurunui at SH1 Bridge record is applied to the rated data. Care was taken to maintain the water balance in the river. Table 2-17 details the mean flows during the record correlation phases. Note the difference in mean flow is caused by a lack of extreme events during the correlation period.

The Hurunui at Mandamus extended record is preferred as the main Hurunui flow dataset.

Table 2-17: The mean flow for Hurunui at SH1 Bridge.

Record	Record Length	Mean Flow (m ³ /s)
Hurunui at SH1 Bridge	1974-1999	72.8
Rated Hurunui at SH1 Bridge*	1974-1999	72.9
Rated Hurunui at SH1 Bridge	1932-2020	66.2

*Prior to superimposing the actual Hurunui at SH1 Bridge record over the HMD series

3 Natural Flows

Natural flows are flows which are uncontrolled, i.e., there is no power station or other control structure upstream of the site. This dataset contains:

- 1) 'Natural' uncontrolled inflows to several reservoirs in New Zealand;
- 2) Modelled natural inflows or tributary inflows to reservoirs, as though they are uncontrolled;
- 3) Flows at gauging stations which could be possible hydro-power schemes in the future.

Many of the natural flows are also actual flows. The methodologies used to create these flow sites have been discussed in Section 2, they will not be repeated in this section. A list of these flow sites and the corresponding section is included in Sections 3.1 and 3.2 for the North and South Islands respectively.

Three flow series have been created that simulate what inflows would be without the control structure in place. These are not actual flows; they are hypothetical natural flows and are discussed in Sections 3.2.

3.1 North Island

Each of the North Island natural flow sites and their corresponding methodology section area listed in Table 3-1.

Table 3-1: A list of North Island "natural" flow sites and the corresponding methodology section.

Flow	Model flow name	Flow site number	Section
Taupo	Natural Inflow	62790 (1)	2.1.2
Waikaremoana	Waikaremoana	3650 (1)	2.1.3
Ngaruroro	Whanawhana	123103 (1)	2.1.9
	Kuripapango	123104 (1)	2.1.9
	Chesterhope	123150 (1)	2.1.9
Mohaka	Raupunga	121801 (1)	2.1.10

3.2 South Island

Each of the South Island natural flow sites and their corresponding methodology section area listed in Table 3-2.

Table 3-2: A list of South Island "natural" flow sites and the corresponding methodology section.

Flow	Model flow name	Flow site number	Section
Pukaki	Nat_Puk	98770 (1)	2.2.1
Waitaki P.S. Tribs	Waitaki	98714 (2)	2.2.1
Benmore	Ben_tp	98615 (2)	2.2.1
Manapouri	Manapouri	99550 (1)	2.2.2
Te Anau	Teanau	9570 (1)	2.2.2
Monowai	Mono_Inflow	199540 (1)	2.2.3
Hawea	Hawea	9170 (1)	2.2.4
Wanaka	Wanaka	9154 (1)	2.2.4
Cobb	Cobb	97904 (2)	2.2.5
Lake Onslow	Onslow	175237 (1)	2.2.9
Waiau	Clarence	162105 (1)	2.2.11
	Glenhope	164604 (1)	2.2.11
	Marble Point	164602 (1)	2.2.11
Wairau	Dip Flat	160114 (1)	2.2.12
Hurunui	Mandamus	165104 (1)	2.2.13
	SH 1 Bridge	165101 (1)	2.2.13

4 Average Outflows

Average outflows are the calculated mean total outflows derived from daily average flows. These are calculated for both the Waikato Power Scheme and the Waitaki Power Scheme. These mean total outflows can be used to calculate the tributary factors for use in modelling.

4.1 Waikato Power Scheme

Each of the lakes and their corresponding mean total outflows are listed in Table 4-1.

Table 4-1: A list of the mean total outflow for lakes within the Waikato Power Scheme.

Lake/location	Period Start	Period end	Mean total outflow (m ³ /s)
Aratiatia	1-Jan-1980	31-Dec-2020	154.42
Ohakuri	1-Jan-1980	31-Dec-2020	175.99
Atiamuri	1-Jan-1980	31-Dec-2020	182.15
Whakamaru	1-Jan-1980	31-Dec-2020	188.68
Maraetai	1-Jan-1980	31-Dec-2020	212.07
Waipapa	1-Jan-1980	31-Dec-2020	213.96
Arapuni	1-Jan-1980	31-Dec-2020	221.24
Karapiro	1-Jan-1980	31-Dec-2020	232.52

4.2 Waitaki Power Scheme

Each of the lakes and their corresponding mean total outflows are listed in Table 4-2.

Table 4-2: A list of the mean total outflow for lakes within the Waitaki Power Scheme.

Lake/location	Period Start	Period end	Mean total outflow (m ³ /s)
Tekapo	1-Jan-1980	31-Dec-2020	81.74
Pukaki	1-Jan-1980	31-Dec-2020	162.89
Ohau	1-Jan-1980	31-Dec-2020	79.67
Benmore	1-Jan-1980	31-Dec-2020	343.42
Aviemore	1-Jan-1980	31-Dec-2020	351.18
Waitaki	1-Jan-1980	31-Dec-2020	354.38

References

- Duffy J R, Maslin D C, Freestone H J., 1993. Manapouri and Te Anau – Predevelopment Records. Works Consultancy Services. Wellington.
- Freestone, H.J. & Maslin, D.C, October 1991: *Mangahao Extended Flow Study*, Hydrology Section, Power Engineering, Works Consultancy Services, Wellington.
- Freestone H., Mills G., 1990. Mohaka, Mangahao, Grey, Arnold & Highbank - Extended Flow Study. Works Consultancy Services. Wellington.
- Greer, M., 1994. Hydrological Data Reference Manual Lake Coleridge Inflows Data 1928 to 1993. Works Consultancy Services. Wellington.
- Greer, M.L., Bowler, J.M. & Freestone, H.J., April 1996: *Hydrological Data Reference Manual – Lake Waikaremoana Inflow Data 1929 to 1995*, Hydrology Section, Power Engineering, Works Consultancy Services, Wellington.
- Halliburton, T., 1993. Tributary flows for SPECTRA: Karapiro and Waitaki. ECNZ Fuel Resources Group. Rutherford House, Wellington.
- Maslin D C, Duffy J R, Freestone H J., 1993. Trends in Flow Data - Manapouri Local Inflows, Mangahao, Cobb, Coleridge & Waikato Tributaries. Works Consultancy Services. Wellington
- NEMS, June, 2013: *National Quality Code Schema*, National Environmental Monitoring Standards (NEMS) Version 1.0.
- NZ Government, 1981. Manapouri Te Anau Development Act 1963. New Zealand Gazette, No. 168, pp. 4227-4229.
- Opus, 2010. Generator SPECTRA Update – Issue 8. Data to 30 June 2010. Opus International Consultants, Wellington.
- Opus, 2016. Lakes Taupo and Pukaki Operational Inflows. Report prepared for the Electricity Authority by Opus International Consultants, Wellington. Project no. 3-53206.16.
- Palmer, L., 1992. Extension of Cobb Flow Records. ECNZ Production Control, Rutherford House, Wellington.
- Payne, D., 2005. Additional SPECTRA Investigations 16 September 2005. Opus International Consultants. Wellington.
- Robertson, E., de Silva, Palmer, L., 1989. Spectra Inputs Flow Data Base for Medium term Multi-Reservoir Optimisation and Simulation - Model User's Manual. ECNZ Production Control. Wellington

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