Hydrological Modelling Dataset

Report 2: Flow Series Description and Methodology

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Preface

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

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

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

The HMD consists of three main components:

1. Infrastructure and hydrological constraint attributes

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

2. Flows

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

3. Storage and spill

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

This report describes the second component of the HMD, the flow datasets.

Contents

1 Introduction

This Hydrological Modelling Dataset (HMD) update was requested by the Electricity Authority and includes data to 31 December 2014. This report provides a description of how the flow datasets are derived.

The HMD comprises of six datasets:

- Infrastructure attributes

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

- Hydrological constraints

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

- Actual Flows:

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

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

- Natural flows:

  a) 'Natural' uncontrolled inflows to a number of reservoirs in New Zealand;
  b) Modelled natural inflows or tributary inflows to reservoirs, as though they are uncontrolled; and
  a) 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 usable storage volumes from 1980 to 2014 for the 10 largest hydro lakes in NZ

- Spill volume

Weekly spill flow data for each of the structures downstream of the 10 largest hydro lakes in NZ

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

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 datasets are provided in a separate report – "Hydrological Modelling Dataset: 2015 HMD Flow Series Comparison with SPECTRA 2010".

The following Power Companies have provided data for this update:

- Contact Energy Ltd
- Genesis Energy Ltd
- Todd 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 a number of 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.

1.1 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, and currently Opus International Consultants Ltd (Opus).

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

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

1.2 Quality codes

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

It was recommended that these standards were adopted throughout New Zealand and all data collected be processed and quality coded appropriately. The degree of rigour in which the standard is applied, will depend on the quality of data sought.

The adoption of best practices highlights that New Zealand Quality Schema (NQCS) must contain "Zones of Quality" with a numeric index that increases with improved quality. Each quality zone requires a summary of the expected quality of the environmental data coded at the zone. Missing Record is the poorest quality data because it affects both the data collectors and end users. This fact needed to be reflected by being assigning the lowest zone and code to the data.

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. 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 a gap is filled with correlation with a nearby site. 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, gaps in the Lake Waikaremoana inflow were filled with the median flow and coded as such. The '340' code is used when the data has been 'replicated'. This may occur when whole or parts of years were replicated and entered to fill a piece of missing record. This occurred often between 1931 and 1934 when there were a limited number of sites operating at this time. The last code is '350' where the data is synthetic but is of an unknown origin.

Table 1.1 Description of the quality codes used for the HMD

Code	Description
200	Unknown or non-verified quality
301	Simple arithmetic
310	Correlation
320	Manufactured via calculations or models (Opus)
325	Manufactured by the recording authority
330	Median flow
340	Replicated data
350	Unknown origin

1.3 Dataset construction summary

The HMD data record for any particular flow series is often a composite record derived using different methods for different periods. Table 1.2 (North Island) and Table 1.3 (South Island) list 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). Manufactured (O) denotes the record is manufactured by Opus, 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 actually 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 - North Island flow sites

Flow Site	Period	Quality Code	Code Definition
Arapuni tributaries	01/01/32 - 31/12/14	301	Synthetic – Simple Arithmetic
Karapiro tributaries	01/01/32 - 06/07/47 07/07/47 – 31/12/14	320 301	Synthetic – Manufactured (O) Synthetic – Simple Arithmetic
Tokaanu Linear	01/01/32 - 31/12/14	320	Synthetic – Manufactured (O)
Tokaanu TPD	01/01/32 - 31/12/14	320	Synthetic – Manufactured (O)
Taupo Linear	01/01/32 - 31/12/14	320	Synthetic – Manufactured (O)
Taupo TPD	01/01/32 - 31/12/14	320	Synthetic – Manufactured (O)
Taupo Operational	01/01/32 – 31/12/92 01/01/93 – 31/12/14	310 320	Synthetic - Correlation Synthetic – Manufactured (O)
Rangipo Linear	01/01/32 - 31/12/14	320	Synthetic – Manufactured (O)
Rangipo TPD	01/01/32 - 31/12/14	320	Synthetic – Manufactured (O)
Waikaremoana	01/01/32 - 31/12/14	325	Synthetic – Manufactured (RA)
Matahina	01/01/32 – 31/12/66 01/01/67- 30/06/08 01/07/08 – 30/06/10 01/07/10 – 31/12/14	350 325 320 325	Synthetic - Unknown Synthetic – Manufactured (RA) Synthetic – Manufactured (O) Synthetic – Manufactured (RA)
Wheao	01/01/32 - 01/01/99 02/01/99 - 30/06/08 01/07/08 - 30/06/10 01/07/10 - 31/12/14	310 325 320 325	Synthetic - Correlation Synthetic – Manufactured (RA) Synthetic – Manufactured (O) Synthetic – Manufactured (RA)
Mangahao	01/01/32 – 06/10/97 07/10/97 – 31/12/14	350 325	Synthetic - Unknown Synthetic – Manufactured (RA)
Patea	01/01/32 - 01/01/99 02/01/99 - 30/06/08 01/07/08 - 30/06/10 01/07/10 - 31/12/14	310 325 320 325	Synthetic - Correlation Synthetic – Manufactured (RA) Synthetic – Manufactured (O) Synthetic – Manufactured (RA)
Kaimai	01/01/32 - 10/07/93 11/07/93 - 30/06/08 01/07/08 - 30/06/10 01/07/10 - 31/12/14	310 325 320 325	Synthetic - Correlation Synthetic – Manufactured (RA) Synthetic – Manufactured (O) Synthetic – Manufactured (RA)
Ngaruroro at Whanawhana	01/01/32 - 31/08/60 01/09/60 - 31/12/14	310 200	Synthetic - Correlation Actual
Ngaruroro at Kuripapango	01/01/32 - 19/09/63 20/09/63 - 31/12/14	310 200	Synthetic - Correlation Actual
Ngaruroro at Chesterhope	01/01/32 - 25/11/76 25/11/76 - 31/12/14	310 200	Synthetic - Correlation Actual
Mohaka at Raupunga	01/01/32 - 28/02/57 01/03/57 - 31/12/14	310 200	Synthetic - Correlation Actual

Table 1.3: Quality of HMD flow datasets - South Island flow sites

Flow Site	Period	Quality Code	Code Definition
Waitaki tributaries	01/01/32 - 31/12/14	310	Synthetic – Simple Arithmetic
Benmore	01/01/32 - 31/12/14	320	Synthetic – Manufactured (O)
Benmore t_p	01/01/32 - 31/12/14	320	Synthetic – Manufactured (O)
OhauRes	01/01/32 - 31/12/14	320	Synthetic – Manufactured (O)
Ohau	01/01/32 - 31/12/14	320	Synthetic – Manufactured (O)
Pukaki	01/01/32 - 31/12/14	320	Synthetic – Manufactured (O)
Tekapo + Pukaki	01/01/32 - 31/12/14	310	Synthetic – Simple Arithmetic
Natural Pukaki	01/01/32 - 31/12/14	310	Synthetic – Simple Arithmetic

Flow Site	Period	Quality Code	Code Definition
Tekapo	01/01/32 - 31/12/14	320	Synthetic – Manufactured (O)
Natural Tekapo	01/01/32 - 31/12/14	320	Synthetic – Manufactured (O)
Manapouri (with Mararoa)	01/01/32 – 07/09/69 08/09/69 - 31/12/14	320 310	Synthetic – Manufactured (O) Synthetic – Simple Arithmetic
Manapouri (without Mararoa)	01/01/32 – 01/05/32 02/05/62 – 31/12/14	320 310	Synthetic – Manufactured (O) Synthetic – Simple Arithmetic
Manapouri (water right reduction)	01/01/32 - 31/12/14	320	Synthetic – Manufactured (O)
Te Anau	01/01/32 - 31/12/14	320	Synthetic – Manufactured (O)
Monowai Inflow	01/01/32 – 30/04/77 01/05/77 - 31/12/14	310 320	Synthetic - Correlation Synthetic – Manufactured (O)
Roxburgh tributaries	01/01/32 - 31/12/14	310	Synthetic – Simple Arithmetic
Wanaka	01/01/32 - 31/12/14	200	Actual
Hawea	01/01/32 - 31/12/14	320	Synthetic – Manufactured (O)
Cobb	01/01/32 – 21/11/45 22/11/45 - 30/06/08 01/07/08 – 30/06/10 01/07/10 – 31/12/14	310 325 320 325	Synthetic - Correlation Synthetic – Manufactured (RA) Synthetic – Manufactured (O) Synthetic – Manufactured (RA)
Coleridge	01/01/32 – 31/12/50 01/01/51 – 30/06/08 01/07/08 – 30/06/10 01/07/10 – 31/12/14	320 350 320 325	Synthetic – Manufactured (O) Synthetic - Unknown Synthetic – Manufactured (O) Synthetic – Manufactured (RA)
Highbank	01/01/32 - 30/04/51 01/05/51 - 30/04/98 01/05/98 - 31/05/02 01/06/02 - 30/06/08 01/07/08 - 30/06/10 01/07/10 - 31/12/14	350 325 350 325 320 325	Synthetic - Unknown Synthetic – Manufactured (RA) Synthetic - Unknown Synthetic – Manufactured (RA) Synthetic – Manufactured (O) Synthetic – Manufactured (RA)
Waipori	01/01/32 – 31/12/87 01/01/88 – 16/09/97 17/09/97 – 30/06/10 01/07/10 – 18/05/12 19/05/12 – 31/12/14	350 310 200 310 200	Synthetic - Unknown Synthetic - Correlation Actual Synthetic - Correlation Actual
Grey + Taramakau (no Taipo)	01/01/32 – 31/12/14	320	Synthetic – Manufactured (O)
Clarence at Jollies	01/01/32 - 27/03/34 28/03/34 - 31/12/59 01/01/60 - 31/12/14	340 310 200	Synthetic – Replicated Data Synthetic - Correlation Actual
Waiau at Glenhope	01/01/32 - 31/12/14	310	Synthetic - Correlation
Waiau at Marble Point	01/01/32 - 06/10/67 06/10/67 - 31/12/14	310 200	Synthetic - Correlation Actual
Wairau at Dip Flat	01/01/32 - 29/03/34 30/03/34 - 31/05/51 01/06/51 - 31/12/14	340 310 200	Synthetic – Replicated Data Synthetic - Correlation Actual
Hurunui at Mandamus	01/01/32 - 29/03/34 30/03/34 - 25/10/56 26/10/56 - 31/12/14	340 310 200	Synthetic – Replicated Data Synthetic - Correlation Actual
Hurunui at SH1 Bridge	01/01/32 - 13/12/74 13/12/74 - 18/06/99 18/06/99 - 20/08/00 21/08/00 – 31/12/14	310 200 310 200	Synthetic - Correlation Actual Synthetic - Correlation Actual

1.4 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 (2015). "N" denotes a natural flow, uncontrolled flow, "A" denotes an actual flow, "N+A" denotes a flow that is both actual and natural

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	81.1	A
Karapiro Tribs	Karapiro	92714 (1)	Waikato tributary flow between Taupo and Karapiro PS	92.7	A
Tokaanu	TokaanuTPD	92790 (3)	Non-linear correlations of Taupo natural inflows used to create Tokaanu inflow	53.4	A
Tokaanu	Toka_Linear	22790 (3)	Linear correlations of Taupo natural inflows used to create Tokaanu inflow	53.2	A
Taupo	TaupoTPD	92790 (1)	Sub catchment inflows non-linear functions of Taupo inflows to create Taupo inflows including TPD diversions	157.7	A
Taupo	Taupo_Linear	22790 (1)	Linear correlations of Taupo natural inflows used to create Taupo inflows including TPD diversions	153.6	A
Taupo	Taupo_Oper	42790 (1)	Rating distribution correlates TPD flow and Taupo inflow, from 1993 to 2005 to create Taupo inflows including TPD diversions. Reflects the current operating regime.	152.5	A
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.	35.6	A
Rangipo	Rangi_linear	22790 (2)	Linear correlations of Taupo natural inflows used	28.5	A
Waikaremoana	Waikaremoana	3650 (1)	Waikaremoana Inflows	17.7	N+A
Matahina	Matahina	93254 (1)	Matahina Inflows	64.4	A
Wheao	Wheao	15462(1)	Wheao/Flaxy Power Station outflow	12.9	A
Mangahao	Mangahao	97502(1)	Local inflows	8.6	A
Patea	Patea	34300(1)	Patea Power Station outflow	19.0	A
Kaimai	Wairoa	14130(1)	Kaimai outflows at Ruahihi	11.9	A

Flow	Model flow name	Flow site number	Description	Mean flow (m^3/s)	Type
Ngaruroro	Whanawhana	123103 (1)	Ngaruroro River flow at Ngaruroro at Whanawhana recorder	35.3	N+A
	Kuripapango	123104 (1)	Ngaruroro River flow at Ngaruroro at Kuripapango recorder	17.7	N+A
	Chesterhope	123150 (1)	Ngaruroro River flow at Ngaruroro at Chesterhope recorder	43.8	N+A
Mohaka	Raupunga	121801 (1)	Mohaka River flow at Mohaka at Raupunga	79.9	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 Tideda file

Table 1.5: South Island flow dataset names and mean values derived for this HMD update (2015). "N" denotes a natural flow, uncontrolled flow, "A" denotes an actual flow, "N+A" denotes a flow that is both actual and natural.

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 Power Station	152.5	A
Benmore	Benmore	98614 (4)	Waitaki tributary flow between Lakes Pukaki & Tekapo and Benmore (Separate Tekapo simulation)	125.8	A
	Ben_tp	98615 (2)	Waitaki tributary flow between Lakes Pukaki & Tekapo and Benmore (Combined lakes Tekapo - Pukaki simulation)	124.0	A
Ohau (separate Tekapo model)	OhauRes	98614 (6)	Ohau A only, using flows of 12m^3/s May to Oct and 8m^3/s Nov to Apr	70.6	A
	Ohau	98614 (3)	Ohau B and C only. Assumes all Ohau inflow flows into Ohau B and C	80.6	N+A
Pukaki, Tekapo	Tek_puk	98615 (1)	One combined flow for both Pukaki and Tekapo	208.5	N
Pukaki	Pukaki	98614 (2)	Pukaki + Tekapo for separate Tekapo simulation	206.7	A
Natural Pukaki	Nat_Puk	98770 (1)	Natural Lake Pukaki inflow	126.6	N
Tekapo	Tekapo	98614 (1)	Separate Tekapo simulation	80.2	A
Natural Tekapo	Nat_Tek	98770 (2)	Natural Lake Tekapo Inflow	82.0	N+A
Manapouri	Manawmara	99551 (1)	Manapouri local inflows allowing for Mararoa dirty water spill	137.1	A

Flow	Model flow name	Site number	Description	Mean flow (m^3/s)	Type
Manapouri	Manapouri	99550 (1)	Manapouri local inflows with no Mararoa input	122.6	N
Manapouri	Manareduced	99552 (1)	Manapouri local inflows allowing for Mararoa dirty water spill, 12, 14 and 16m³/s min flow from MLC, flushing and recreational releases from MCL	120.8	A
Te Anau	Teanau	9570 (1)	Te Anau Inflows	283.1	N+A
Monowai	Mono_Inflow	199540 (1)	Monowai Power Station inflow	13.0	N+A
Roxburgh	Roxburgh	99110 (1)	Roxburgh tributary flows – but excluding Hawea outflows	445.3	A
Wanaka	Wanaka	9154 (1)	Wanaka outflows	196.7	N+A
Hawea	Hawea	9170 (1)	Hawea Inflows	64.8	N+A
Cobb	Cobb	97904 (2)	Cobb inflows	5.4	N+A
Coleridge	Coleridge	97904 (1)	Coleridge inflows	24.7	A
Highbank	Highbank	7968(1)	Highbank Power Station outflow	13.4	A
Waipori	Waipori	174395(1)	Waipori Power Station outflow	7.4	A
Grey+Taramakau-Taipo	Grey_tara	77106(1)	Grey River at Dobson including Taramakau but not Taipo	436.2	A
Waiau	Clarence	162105 (1)	Waiau River flow at Clarence at Jollies recorder	14.5	N+A
	Glenhope	164604 (1)	Waiau River flow at Waiau at Glenhope recorder	33.4	N+A
	Marble Point	164602 (1)	Waiau River flow at Waiau at Marble Point recorder	94.4	N+A
Wairau	Dip Flat	160114 (1)	Wairau River flow at Wairau at Dip Flat recorder	26.5	N+A
Hurunui	Mandamus	165104 (1)	Hurunui River flow at Hurunui at Mandamus recorder	51.4	N+A
	SH 1 Bridge	165101 (1)	Hurunui River flow at SH1 Bridge	66.6	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 Tideda file

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 Jul 1947 – 1 Jul 1997) and are simulated from Arapuni tributary flows, scaled up by 20%, for the period before 1947 (Halliburton, December 1993).

In 2008 the Karapiro outflows were recalculated and updated back to 1995. This was because analysis showed that PI data from Karapiro Power Station using unit flow efficiency curves provided a better match.

2.1.2 Tokaanu, Taupo and Rangipo

Preface

The Tongariro Power Development simulation was extensively revised (Henderson, 1996) to incorporate minimum flow rules at Te Maire on the Whanganui River, at Turangi and Poutu Intake on the Tongariro River, and different rules about spill at Rangipo Intake and flows at Waikato Falls. Several logical errors in the previous simulation (pre-1996) were corrected. Consequences of the changes introduced were:

- 2.5m^3/s increase in Taupo inflows
- 6.2m^3/s increase in Rangipo flows
- 2.1m^3/s decrease in Tokaanu flows
- 1.2m^3/s increase in Western Diversion flows

These average flow changes are for the 62 years from 1 Jan 1932 to 30 Jun 1994. The previous simulation has been retained within the modelling process but operates independently of the modified simulation. The outputs from the two simulations are kept separate. Output from the original simulation is stored as site 22790 and output from the new simulation is stored as site 92790. Thus, site 22790 has been superseded by site 92790.

The TPD processing scripts and PSIMs are very complicated and may need revising to reflect current operation practices. This issue will be discussed with Genesis to ensure the scripts are still producing output that is consistent with operational practices.

A third methodology for Taupo inflows incorporating TPD flows is also used i.e. Site 42790. This more accurately represents the current TPD operating regime. Data for these three flows sites is calculated assuming current infrastructure was in place back in 1932.

HMD flow records

For the HMD modelling, the required flows associated with the Tongariro Power Development (TPD) are those inflows available for generation at Tokaanu and Rangipo Power Stations and the inflows to Lake Taupo. To determine these flows however, several component flows at diversion points must first be determined. A series of operations using recorded data from the rivers, reservoirs and diversion canals of the TPD culminate in two Tideda simulation programs called "TAUPOFUN.SIM" and "TAUPOTPD.SIM" which model the river flows and current scheme operation respectively. These two simulation programs supersede the original simulation program TAUPO.SIM.

A third Lake Taupo inflow (with TPD) dataset is modelled. The linear dataset (site number 22790) was the original dataset for TPD flow calculation. It has now been superseded by the TPD datasets (site number 92790) but is still included for historic reference. The 92790 TPD datasets should be used.

An additional TPD dataset has been created in this HMD update. This operational inflow dataset (site number 42790) more accurately represents the true TPD operating regime, as specified in the 1992 Waikato River consent hearing. An outcome from this hearing was a decrease in the diversion take as residual flow in the Whakapapa Stream was increased to $3m^3/s$. This flow site differs from the 92790 TPD dataset which also adjusts for post 1992 hearing conditions, but does not optimise diversion flows. Site 42790 is based on the actual operating regime of the TPD diversion from 1993 to 2005.

Process to calculate TPD flow sites

1. Net Taupo outflows

Subtract recorded diversion flows (Wairehu Canal and Moawhango Tunnel) from Taupo outflows to give net Taupo outflows.

2. Taupo natural inflows

Use natural inflows data from the Power Archive.

3. Outline of TAUPOFUN.SIM

Use full record of Taupo Natural Inflows 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

4. 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.

5. 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.

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 41.6m^3/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 (29m^3/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. At times this means 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. Waihohonu 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 (0.6m^3/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, is the last to be determined. This is achieved by subtracting the diverted component of the natural Tongariro flows from the Taupo Natural inflows and then adding the total flow diverted into Lake Rotoaira.

Taupo Operational Inflow - TPD flows were correlated with the calculated Taupo actual 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 actual inflows. This synthetic TPD flow dataset was added to Taupo natural inflows to represent inflow including TPD back to 1932, i.e., current infrastructure as if it existed from 1932. From 1 Sep 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 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 has calculated Waikaremoana inflows directly. Data supplied for this HMD update suffered from negative inflows because of leakage associated with Lake Waikaremoana. Negative inflows supplied prior to 2006 were set to zero but as this is an ongoing problem, data are now presented as supplied, including negatives. Until this problem is rectified negative inflows will exist in the Waikaremoana dataset. Genesis 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.

The various data sets necessary to produce a record of daily inflows were not available for the 2010 SPECTRA update. Therefore, daily inflows for 1 July 2008 to 30 June 2010 had to be estimated from the metered generation data provided to the Electricity Authority.

Rather than relying on published average station efficiency information, an empirical relationship between daily inflows and daily generation was developed using data from the 2008 SPECTRA Update. During this period the average daily inflows had been calculated. The potential impact of various resource consent conditions on station flow were not considered beyond establishing any residual flows and the maximum station capacity. Having developed the empirical relationship, it was used to ‘predict’ the average daily inflows for the period from 2008 to 2010.

Obviously such an approach has a number of assumptions and limitations. These include:

- That daily inflow equals daily outflow and therefore the station functions essentially as a run-of-the-river scheme. Since the Matahina Dam has a small storage capacity this assumption is likely to be valid.
- That there is no spill flow, or any other flow that does not pass through the turbines. While generally this is the case, it is possible that the inflow series slightly under-estimates inflows during any major flow event which cannot be contained behind the dam.
- It assumes that all electricity is generated at the ‘average efficiency’ of the station. This will not be the case, but the resulting errors are likely to be small.
- It ignores the requirement of some stations to provide residual flow downstream of the station.
- It ignores the potential impact of flood rules and other operational and management decisions that can affect either station operation or spill.

To confirm that the inflow data generated in the above manner accurately reflects the inflows calculated in previous SPECTRA updates, the two sets of data were compared over a common period (Figure 2.1). Flows were removed if they were above the maximum generation available from the machines; in this case 150m³/s. Only 24 flow points were removed from the dataset (2.2%).

The average daily inflow record created for the 2010 SPECTRA Update is likely to be slightly conservative i.e., estimated inflows are slightly less than actual inflows. This is because any spill flows have not been considered and added to the flows used to generate electricity. However, spill magnitudes and durations are small so the overall effect on synthesised flow regime is likely to be minor. Also, since the energy generation potential of the rivers is most strongly related to average flow conditions any error is likely to be of little significance.

Some flow sites are not recalculated as part of the HMD process. 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.

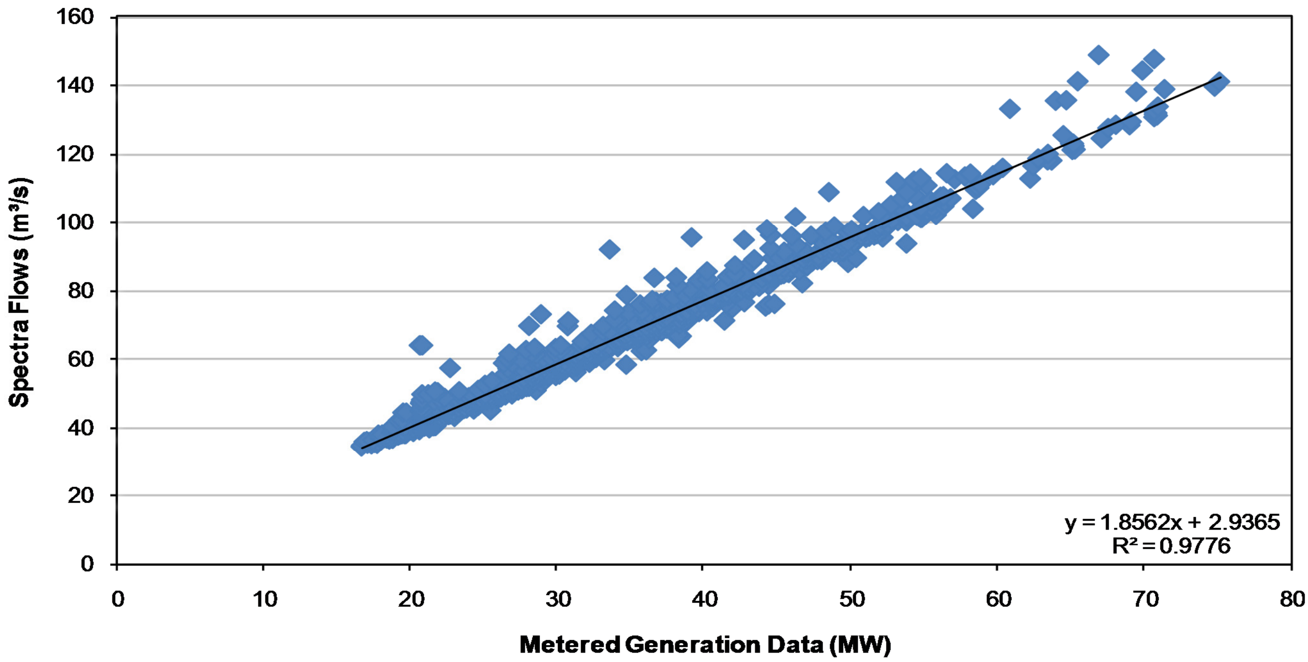

Figure 2.1: Comparison between the generation data and the SPECTRA flows

2.1.5 Wheao/Flaxy

Data for the Wheao Power Station outflows was supplied by Trustpower from 1999 to 2008 and from 2010 to 2014. It was therefore necessary to extend this record back from 1999 to 1932. Data was available from Rangitaiki at Murapara from 1948 to 2008.

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.

The various data sets necessary to produce a record of daily inflows were not available for the 2010 SPECTRA update. Therefore, daily inflows had to be estimated from the metered generation data provided to the Electricity Authority from 1 July 2008 to 30 June 2010.

Rather than relying on published average station efficiency information, an empirical relationship between daily inflows and daily generation was developed using data from the 2008 SPECTRA Update. During this period the average daily inflows was calculated. The potential impact of various resource consent conditions on station flow were not considered beyond establishing any residual flows and the maximum station capacity. Having developed the empirical relationship, it was used to 'predict' the average daily inflows for the period from 2008 to 2010.

Obviously such an approach has a number of assumptions and limitations. These include:

- That daily inflow equals daily outflow and therefore the station functions essentially as a run-of-the-river scheme. Since Wheao Dam has small storage capacity this assumption is likely to be valid.
- That there is no spill flow, or any other flow that does not pass through the turbines. While generally this is the case, it is possible that the inflow series slightly under-estimates inflows during any major flow event which cannot be contained behind the dam.
- It assumes that all electricity is generated at the 'average efficiency' of the station. This will not be the case, but the resulting errors are likely to be small.
- It ignores the requirement of some stations to provide residual flow downstream of the station.
- It ignores the potential impact of flood rules and other operational and management decisions that can affect either station operation or spill.

To confirm that the inflow data generated in the above manner accurately reflects the inflows calculated in previous SPECTRA updates, the two sets of data were compared over a common period (Figure 2.2).

The average daily inflow record created for the 2010 SPECTRA Update is likely to be slightly conservative i.e., estimated inflows are slightly less than actual inflows. This is because any spill flows have not been considered and added to the flows used to generate electricity. However, spill magnitudes and durations are small so the overall effect on synthesised flow regime is likely to be minor. Also, since the energy generation potential of the rivers is most strongly related to average flow conditions any error is likely to be of little significance.

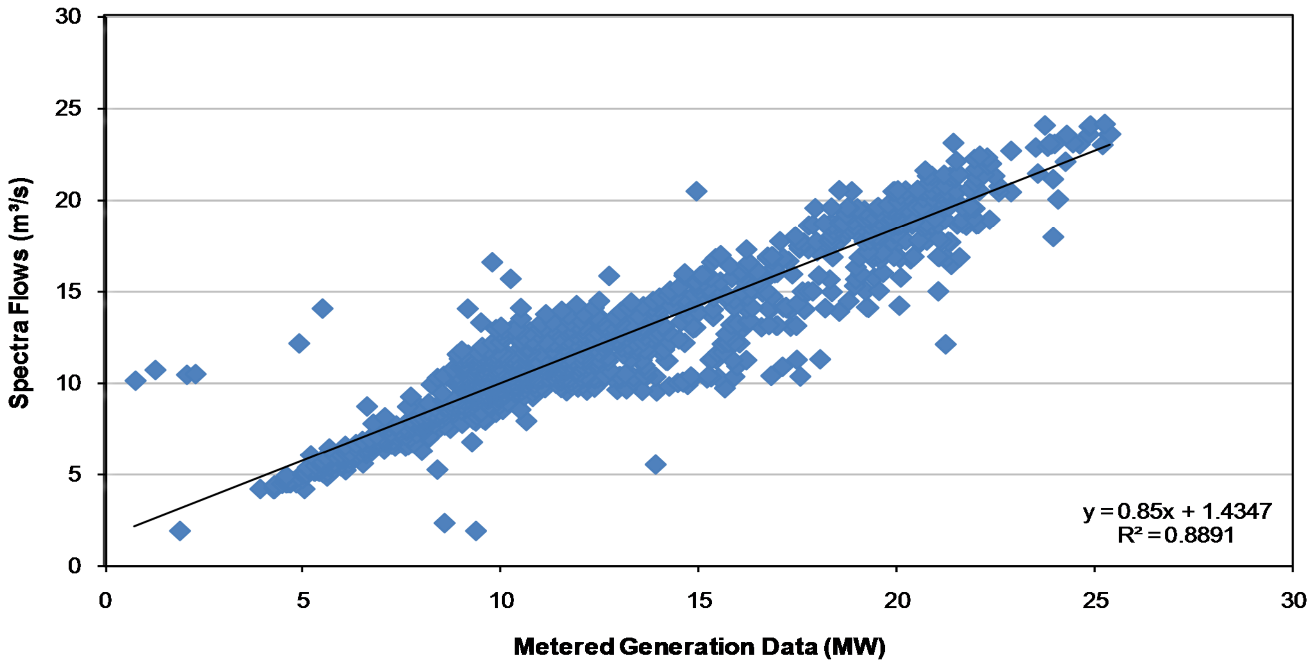

Figure 2.2: Comparison between the generation data and the HMD flows

This flow site is not recalculated back to 1932 as part of the HMD process. 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: Mean outflow for actual and synthetic Wheao power station data

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	1932-2014	12.9

*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 particular 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 accusonic 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 $8m^3/s$ 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 recent data suggests that $12m^3/s$ 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, it would appear that 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 Oct 1997 to 31 Dec 2014 are actual data. Inflow data are based on spill from the No. 2 dam and machine generation, i.e. outflows. The Todd Group have noted however, that the communications cable downstream of No2 Dam has had issues and will be replaced in the future. Consequently, spill data since 28-April-2013 is unreliable and has been replaced with spill data from No1 Dam. This should be quite accurate but does not include spill flows less than $1m^3/s$.

This flow site was not recalculated as part of the HMD process. Discussion with the recording authority advised there were no changes to the previous dataset. The data was supplied by Todd Group and was 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.

The various data sets necessary to produce a record of daily inflows were not available for the 2010 SPECTRA update. Therefore, daily inflows had to be estimated from the metered generation data provided to the Electricity Authority for the period 1 July 2008 to 30 June 2010.

Rather than relying on published average station efficiency information, an empirical relationship between daily inflows and daily generation was developed using data from the 2008 SPECTRA Update. During this period the average daily inflows had been calculated. The potential impact of various resource consent conditions on station flow were not considered beyond establishing any residual flows and the maximum station capacity. Having developed the empirical relationship, it was used to 'predict' the average daily inflows for the period from 2008 to 2010.

Obviously such an approach has a number of assumptions and limitations. These include:

- That daily inflow equals daily outflow and therefore the station functions essentially as a run-of-the-river scheme.
- That there is no spill flow, or any other flow that does not pass through the turbines. While generally this is the case, it is possible that the inflow series slightly under-estimates inflows during any major flow event which cannot be contained behind the dam.
- It assumes that all electricity is generated at the 'average efficiency' of the station. This will not be the case, but the resulting errors are likely to be small.
- It ignores the requirement of some stations to provide residual flow downstream of the station.
- It ignores the potential impact of flood rules and other operational and management decisions that can affect either station operation or spill.

To confirm that the inflow data generated in the above manner accurately reflects the inflows calculated in previous SPECTRA updates, the two sets of data were compared over a common period (Figure 2.3). Flows below $2m^3/s$ have been removed from the dataset because of consent conditions; Patea Dam must maintain a mean 24-hour flow of at least $2m^3/s$. Two years of data were used for this flow site as the dataset for 2006 to 2008 contained numbers directly obtained from flow correlation. The dam also times spillway operations to facilitate migration of mature eels downstream. Both these activities lead to a high degree of scatter in the relationship between generation and flow.

The average daily inflow record created for the 2010 SPECTRA Update is likely to be slightly conservative i.e., estimated inflows are slightly less than actual inflows. This is because any spill flows have not been considered and added to the flows used to generate electricity. However, spill magnitudes and durations are small so the overall effect on synthesised flow regime is likely to be minor. Also, since the energy generation potential of the rivers is most strongly related to average flow conditions any error is likely to be of little significance.

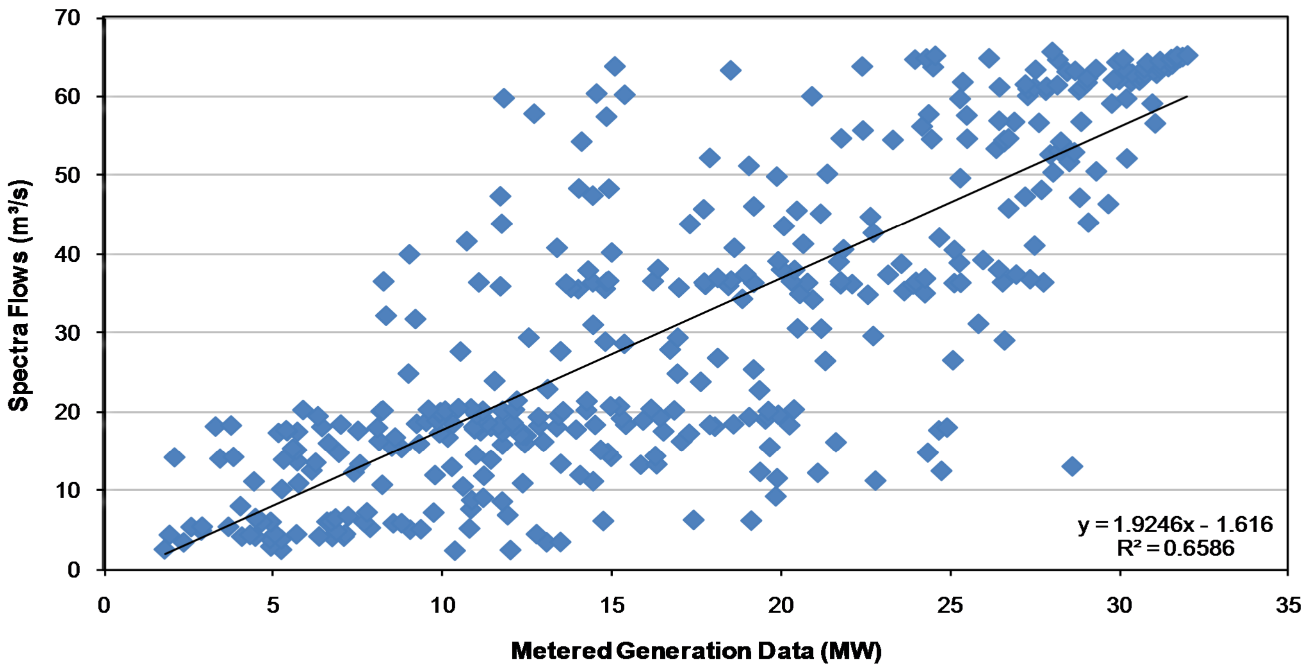

Figure 2.3: Comparison between the generation data and the HMD flows

This flow site is not recalculated back to 1932 as part of the HMD process. 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: 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	1932-2014	19.0

*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 and synthetic data were combined to provide a flow record for Wairoa at Power Station from 1932 to 2008.

The various data sets necessary to produce a record of daily inflows were not available for the 2010 SPECTRA update. Therefore, daily inflows had to be estimated from the metered generation data provided to the Electricity Authority from 1 July 2008 to 30 June 2010.

Rather than relying on published average station efficiency information, an empirical relationship between daily inflows and daily generation was developed using data from the 2008 SPECTRA Update. During this period the average daily inflows were calculated. The potential impact of various resource consent conditions on station flow were not considered beyond establishing any residual flows and the maximum station capacity. Having developed the empirical relationship, it was used to 'predict' the average daily inflows for the period from 2008 to 2010.

Obviously such an approach has a number of assumptions and limitations. These include:

- That daily inflow equals daily outflow and therefore the station functions essentially as a run-of-the-river scheme. Since the Ruahihi Dam has a small storage capacity this assumption is likely to be valid.
- That there is no spill flow, or any other flow that does not pass through the turbines. While generally this is the case, it is possible that the inflow series slightly under-estimates inflows during any major flow event which cannot be contained behind the dam.
- It assumes that all electricity is generated at the 'average efficiency' of the station. This will not be the case, but the resulting errors are likely to be small.
- It ignores the requirement of some stations to provide residual flow downstream of the station.
- It ignores the potential impact of flood rules and other operational and management decisions that can affect either station operation or spill.

To confirm that the inflow data generated in the above manner accurately reflects the inflows calculated in previous SPECTRA updates, the two sets of data were compared over a common period (Figure 2.4). Data points were removed from the correlation if the SPECTRA data was equal to 0. Flows were removed if they were above the maximum generation available from the machines; in this case 25m^3/s. Only six flow points were removed from the dataset (0.4%).

The average daily inflow record in the 2010 SPECTRA Update is likely to be slightly conservative i.e., estimated inflows are slightly less than actual inflows. This is because any spill flows have not been considered and added to the flows used to generate electricity. However, spill magnitudes and durations are small so the overall effect on synthesised flow regime is likely to be minor. Also, since the energy generation potential of the rivers is most strongly related to average flow conditions any error is likely to be of little significance.

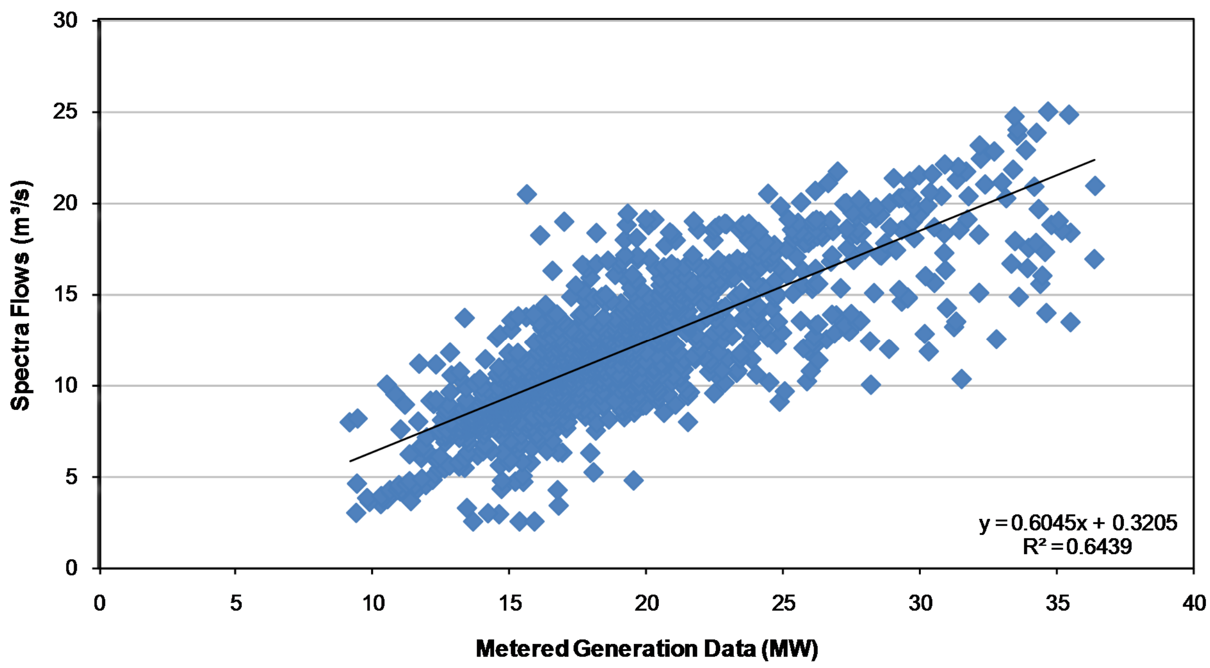

Figure 2.4: Comparison between generation data and HMD flows

This flow site is not recalculated back to 1932 as part of the HMD process. 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: Mean outflows 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	1932-2014	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.

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 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	1932-2014	35.3

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

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	1931-2014	17.7

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

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	1932-2014	43.8

*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 Jan 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 similar to 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: Mohaka at Raupunga mean flow

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	1932-2014	79.9

*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.

Pukaki and Tekapo inflows

Three options are modelled:

1. Aggregate both lakes into one, and scale Tekapo A and B cumecs/MW factors by the ratio of the mean flows to ensure the correct mean generation from the combined flow. Flow set: *Tek_Puk* (Total inflows to both lakes) – this is a modelled natural series
2. Two-lake simulation of Tekapo-Pukaki system (i.e. separate Tekapo simulation). Lake Tekapo treated separately with a stand-alone Tideda simulation of its operation. This accounts for bottleneck effect of the canal. Flow sets: Tekapo (trib), Pukaki (including Tekapo outflow. '*Pukaki'* is a hypothetical actual flow, not a natural flow series; and
3. Natural Inflows to each lake separately. Flow sets: Nat_tek and *Nat_puk*.. Natural inflows to Lake Tekapo are also actual flows. Natural inflows to Lake Pukaki is a simulated natural series.

Ohau

Ohau A is affected by residual flows in the Upper Ohau River.

Two simulations are run for Ohau based on a separate Tekapo simulation of Tekapo - Pukaki system:

1. Ohau - Ohau B & C only, no loss of water; and
2. OhauRes - Residual flows diverted to the Upper Ohau River of $8m^3/s$ (Nov to Apr) and $12m^3/s$ (May to Oct).

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:

1. Benmore (mean of 125.4m³/s) is based on the separate Tekapo simulation and includes Tekapo spill.
2. Benmore_tp (mean of 123.5m³/s) is based on the combined lakes Tekapo-Pukaki simulation and is simply Ohau inflow plus Ahuriri scaled up by 1.33.

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 Aug 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 a number of 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 Apr 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, October 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 (April 1989) and later confirmed by Maslin et al (February 1993).

Several options are available for the Manapouri flows:

1. With Mararoa diversion (*Manawmara*). 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.
2. Without Mararoa (Manapouri), which represents the view of a possible extreme outcome of water rights application. This is a hypothetical natural flow, not an actual flow series.
3. With the minimum flow regime implemented and Mararoa dirty water spill (*Manareduced*). 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 Jan 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.

The inflow is now calculated using the Opus inflow regime and has been recalculated back to May 1977 for the 2015 update due to 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.

Table 2.8: Monowai mean flow

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 – Opus Inflows	1932 - 2014	13.0

2.2.4 Clutha

HMD flow records

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

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

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

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, January 1992 and Maslin et al, February 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 Mar 1934 to Nov 1945 the inflows are based on a correlation with Gowan at Rotoroa. From Nov 1945 to present, the inflows are calculated from actual outflow records with an allowance for change in lake storage.

The various data sets necessary to produce a record of daily inflows were not available for the 2010 SPECTRA update. Flows were therefore derived using a correlation between the Cobb at Trilobite flows and the Cobb inflows from 2008 SPECTRA update. Daily average flows from both flow sites were used to obtain flow duration curves. These were then correlated using both linear and polynomial regressions (Figure 2.5).

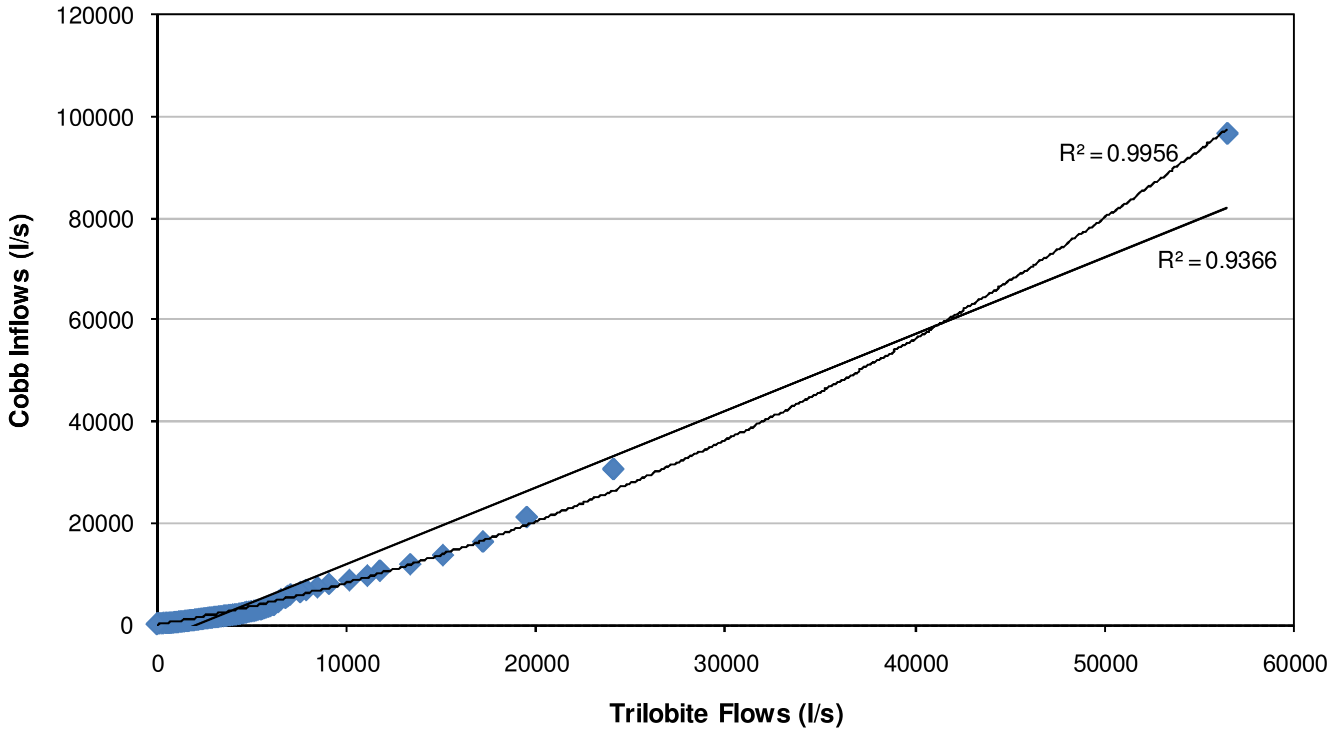

Figure 2.5: Regression lines for the Trilobite and Cobb Inflows (1-Jan-2000 to 30 Jun-2008)

Rather than relying on published average station efficiency information, an empirical relationship between daily inflows and daily generation was developed using data from the 2008 SPECTRA Update. During this period the average daily inflows had been calculated. The potential impact of various resource consent conditions on station flow were not considered beyond establishing any residual flows and the maximum station capacity. Having developed the empirical relationship, it was used to 'predict' the average daily inflows for the period from 1 July 2008 to 30 June 2010.

Obviously such an approach has a number of assumptions and limitations. These include:

- That daily inflow equals daily outflow and therefore the station functions essentially as a run-of-the-river scheme.
- That there is no spill flow, or any other flow that does not pass through the turbines. While generally this is the case, it is possible that the inflow series slightly under-estimates inflows during any major flow event which cannot be contained behind the dam.
- It assumes that all electricity is generated at the 'average efficiency' of the station. This will not be the case, but the resulting errors are likely to be small.
- It ignores the requirement of some stations to provide residual flow downstream of the station.
- It ignores the potential impact of flood rules and other operational and management decisions that can affect either station operation or spill.

To confirm that the inflow data generated using the polynomial regression accurately reflects the inflows calculated in previous SPECTRA updates, the two sets of data were compared over a common period. Data was also synthesised using the polymomial equation for the Cobb inflow series between Jan 2000 and Jun 2008. This was then correlated with the Cobb inflows estimated from station records for the same period (Figure 2.6). The r^2 value is quite low but these data are the best available at this time.

The average daily inflow record in the 2010 SPECTRA Update is likely to be slightly conservative i.e., estimated inflows are slightly less than actual inflows. This is because any spill flows have not been considered and added to the flows used to generate electricity. However, spill magnitudes and durations are small so the overall effect on synthesised flow regime is likely to be minor. Also, since the energy generation potential of the rivers is most strongly related to average flow conditions any error is likely to be of little significance.

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

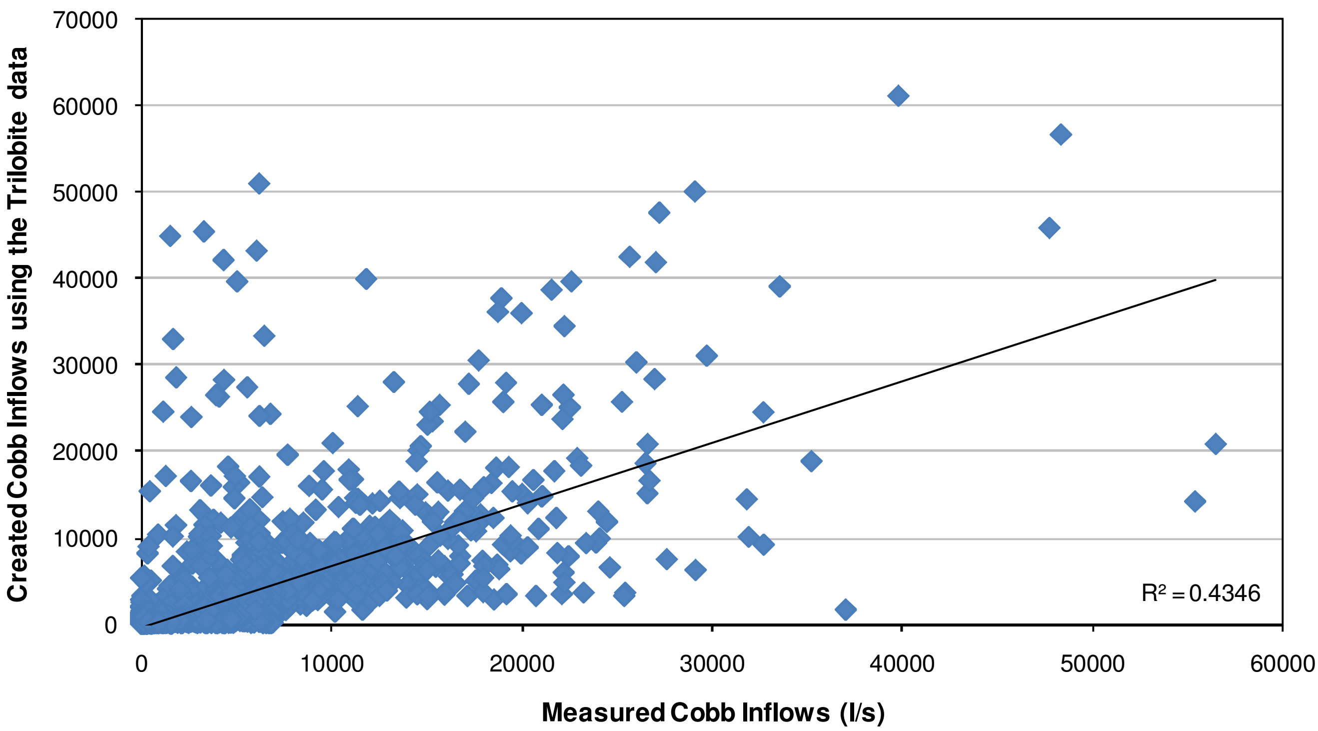

Figure 2.6: Linear regression line for the measured and calculated Cobb Inflow series (1-Jan-2000 to 30 Jun-2008)

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:

Inflow = outflow ± 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, Sept. 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 Apr 1951 to Sep 1963. It did not significantly affected the mean flow. Note that the efficiency of the diversion works varies and this may affect flow trends. Data from 26 Jan 1998 to 31 Dec 2002 is synthetic record.

The various data sets necessary to produce a record of daily inflows were not available for the 2010 SPECTRA update. Instead, Trustpower provided daily inflows derived from a water balance for the 1 July 2008 to 30 June 2010.

To compare whether the inflow data generated in the above manner accurately reflects the inflows calculated in previous SPECTRA updates, two sets of data were compared over a common period (Figure 2.7). The ‘2008 method’ is the usual method used by SPECTRA which uses the change in storage and outflows from Lake Coleridge. The ‘2010 method’ is simply a water balance. The relationship between the two different methods is generally poor, although the two patterns are similar. Despite this apparent anomaly these are the only inflow data available for the update.

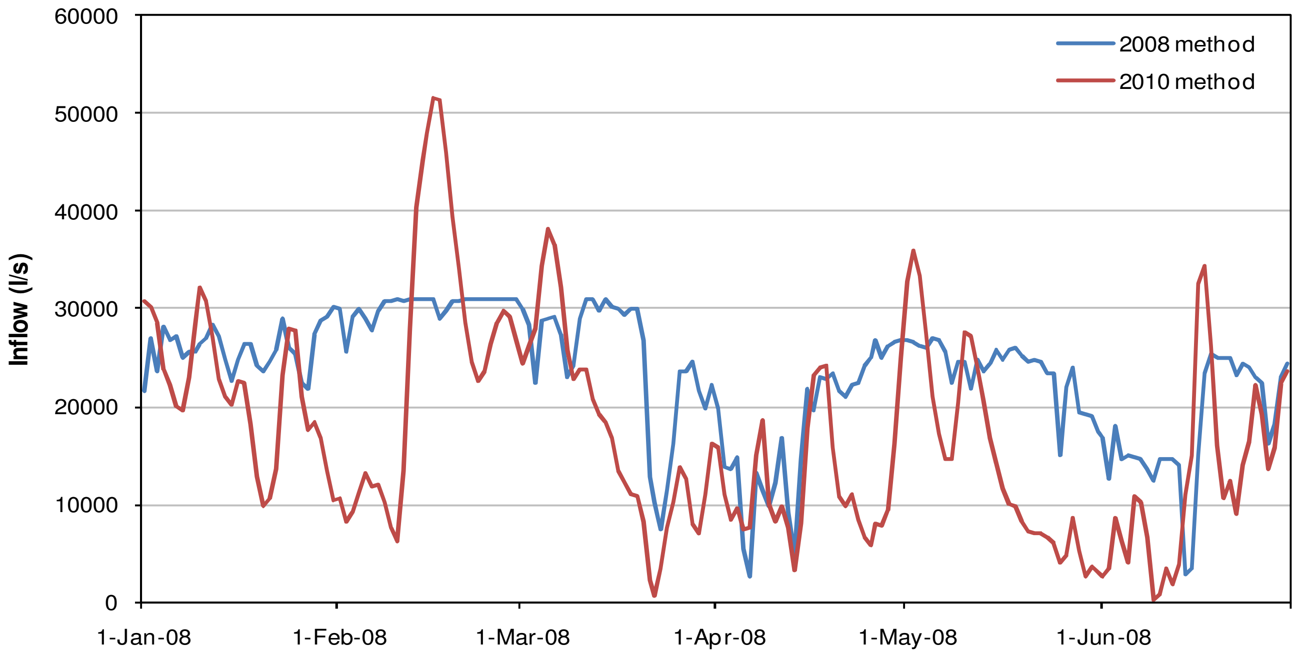

Figure 2.7: Coleridge Inflows created using two different methods (1-Jan to 1-Jul 2008). The 2008 method uses the outflows and change in storage measured at the Power Station Intake. The 2010 method is a water balance.

This flow site is not recalculated back to 1932 as part of the HMD process. 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 Opus 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.

The various data sets necessary to produce a record of daily inflows were not available for the 2010 SPECTRA update. Therefore, daily inflows had to be estimated from the metered generation data provided to the Electricity Authority 1 July 2008 to 30 June 2010.

Rather than relying on published average station efficiency information, an empirical relationship between daily inflows and daily generation was developed using data from the previous SPECTRA

Update. During this period the average daily inflows had been calculated. The potential impact of various resource consent conditions on station flow were not considered beyond establishing any residual flows and the maximum station capacity. Having developed the empirical relationship, it was used to 'predict' the average daily inflows for the period from 2008 to 2010.

Obviously such an approach has a number of assumptions and limitations. These include:

- That daily inflow equals daily outflow and therefore the station functions essentially as a run-of-the-river scheme. Since the Highbank dam has a small storage capacity this assumption is likely to be valid.
- That there is no spill flow, or any other flow that does not pass through the turbines. While generally this is the case, it is possible that the inflow series slightly under-estimates inflows during any major flow event which cannot be contained behind the dam.
- It assumes that all electricity is generated at the 'average efficiency' of the station. This will not be the case, but the resulting errors are likely to be small.
- It ignores the requirement of some stations to provide residual flow downstream of the station.
- It ignores the potential impact of flood rules and other operational and management decisions that can affect either station operation or spill.

To confirm that the inflow data generated in the above manner accurately reflects the inflows calculated in previous SPECTRA updates, the two sets of data were compared over a common period (Figure 2.8).

The average daily inflow record in the 2010 SPECTRA Update is likely to be slightly conservative i.e., estimated inflows are slightly less than actual inflows. This is because any spill flows have not been considered and added to the flows used to generate electricity. However, spill magnitudes and durations are small so the overall effect on synthesised flow regime is likely to be minor. Also, since the energy generation potential of the rivers is most strongly related to average flow conditions any error is likely to be of little significance.

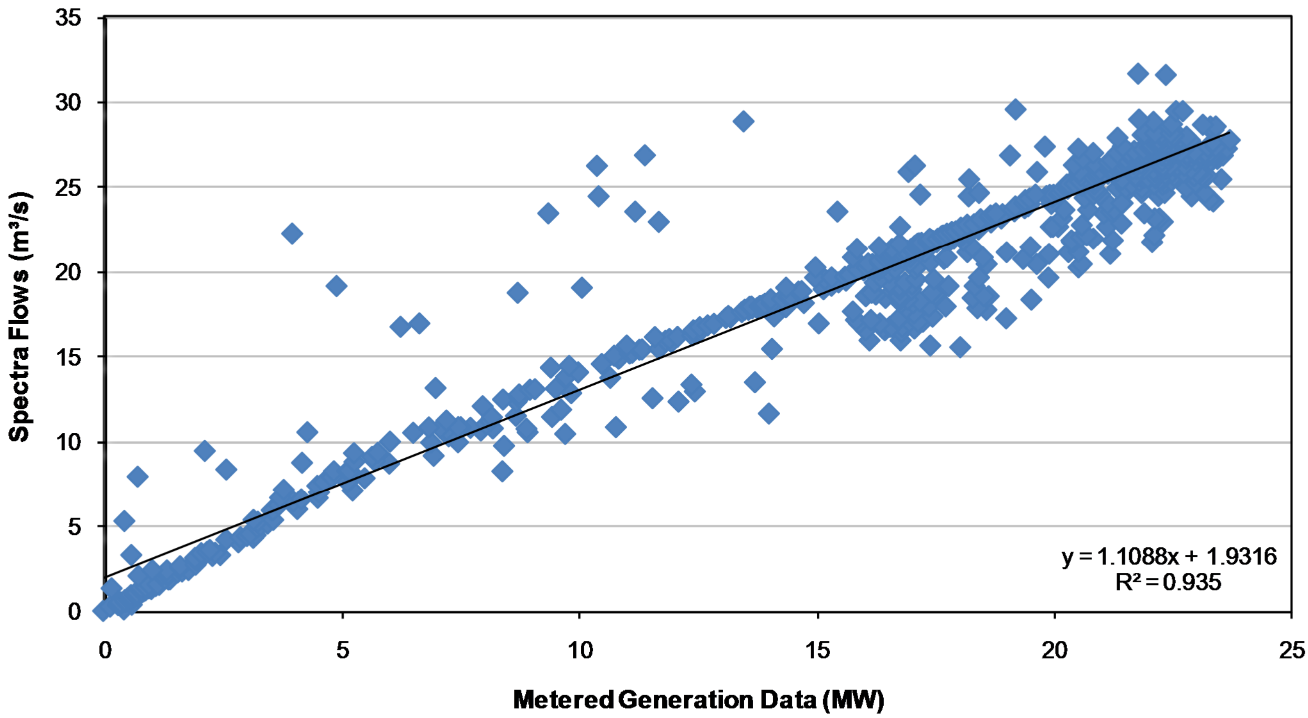

Figure 2.8: Comparison between generation data and HMD flows

This flow site is not recalculated back to 1932 as part of the HMD process. 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: Mean outflows for Highbank Power Station

Record	Record Length	Mean Flow (m^3/s)
Highbank actual (ECNZ)	1951-1988	13.7
Highbank actual (Trustpower)	2002-2008	11.8
Synthetic Highbank	1931-2007	14.2
Actual and synthetic Highbank	1932-2014	13.4

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 2.9 shows a flow hydrograph for Waipori at Below No 4 power station.

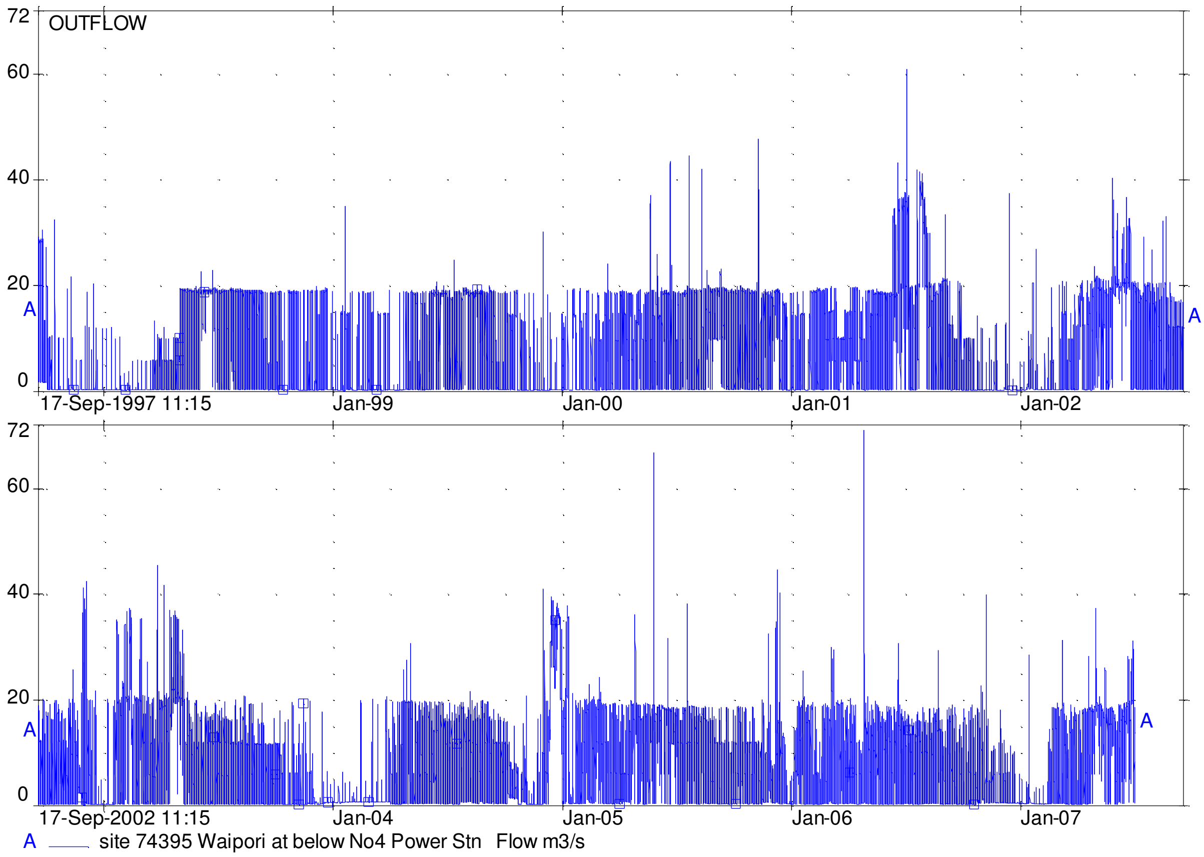

Figure 2.9: Waipori at Below No 4 Power Station flow

Figure 2.10 highlights how the Waipori catchment does not reflect the behaviour of the surrounding catchments. Figure 2.10 shows Waipori at Below No 4 power station versus Lake Wakatipu outflow. It can be seen that 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.

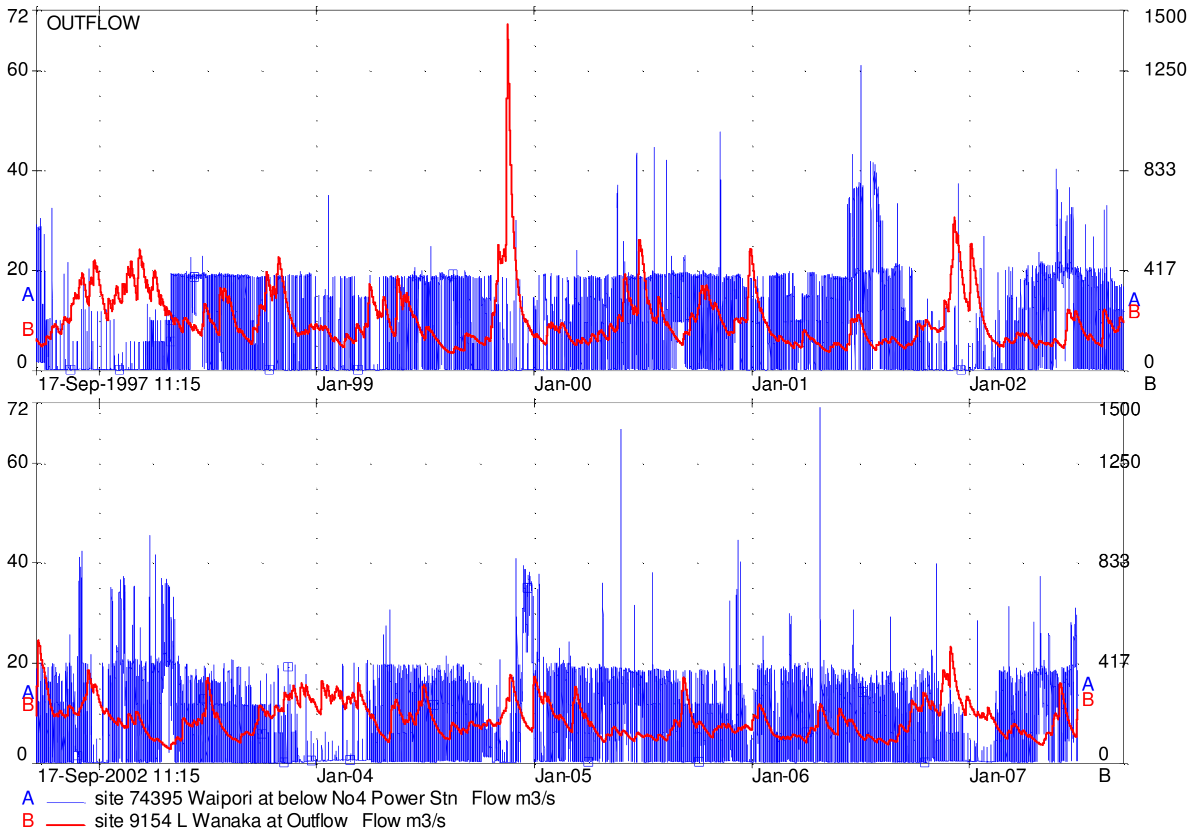

Figure 2.10: Waipori at Below No 4 Power Station flow compared with Lake Wanaka Outflow

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 the HMD process. 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: 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	1932-2014	7.4

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

2.2.9 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:

1. Residual flows are required in the Taramakau and Taipo Rivers of $15m^3/s$ and $5m^3/s$ respectively
2. Maximum canal flow is $230m^3/s$ (twice the mean)
3. Shut down of diversion structure intake during floods is not considered
4. 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, post-1979.

The data set including Taramakau only 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.

It should be noted that NIWA (as at June 2015) is considering whether to keep the Taipo and Taramakau flow sites open.

2.2.10 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).

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 2.11 details the mean flows during the record correlation phases. This flow has remained constant.

Table 2.11: Clarence at Jollies mean flow

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	1932-2014	14.5

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

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.

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 is not rated any longer (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 (2.3m^3/s (6%) lower).

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 fairly constant.

Table 2.12: Waiau at Glenhope mean flow

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	1932-2014	33.4

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

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 Feb 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 2.13 details the mean flows during the record correlation phases. This flow has remained fairly constant.

Table 2.13: Waiau at Marble Point mean flow

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	1932-2014	94.4

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

The slightly lower mean flow for the longer record (1932 to 2014) is because of a dry period in the 1930s, and the reduced flood activity in the synthetic record.

2.2.11 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.

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 Apr 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 2.14 details the mean flows during the record correlation phases.

Table 2.14: Wairau at Dip Flat mean flow

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	1932-2014	26.5

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

2.2.12 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.

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 2.15 details the mean flows during the record correlation phases.

Table 2.15: Hurunui at Mandamus Bridge mean flow

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	1932-2014	51.4

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

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 Jun 1999 and Jul 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 2.16 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 2.16: Hurunui at SH1 Bridge mean flow

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	1932-2014	66.6

*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:

a) 'Natural' uncontrolled inflows to a number of reservoirs in New Zealand;
b) Modelled natural inflows or tributary inflows to reservoirs, as though they are uncontrolled; and
b) 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: List of North Island "natural" flow sites and the corresponding methodology section

Flow	Model flow name	Flow site number	Section
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 North Island natural flow sites and their corresponding methodology section area listed in Table 3.2.

Table 3.2: List of South Island "natural" flow sites and the corresponding methodology section

Flow	Model flow name	Flow site number	Section
Waitaki P.S. Tribs	Waitaki	98714 (2)	2.2.1
Benmore	Ben_tp	98615 (2)	2.2.1

Flow	Model flow name	Flow site number	Section
Natural Pukaki	Nat_Puk	98770 (1)	3.2.1
Natural Tekapo	Nat_Tek	98770 (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
Waiau	Clarence	162105 (1)	2.2.10
	Glenhope	164604 (1)	2.2.10
	Marble Point	164602 (1)	2.2.10
Wairau	Dip Flat	160114 (1)	2.2.11
Hurunui	Mandamus	165104 (1)	2.2.12
	SH 1 Bridge	165101 (1)	2.2.12

3.2.1 Pukaki and Tekapo combined natural inflows, and Pukaki natural inflows

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.

Pukaki and Tekapo inflows - Three options are available (two of these are modelled 'natural' flows):

1. Aggregate both lakes into one, and scale Tekapo A and B cumecs/MW factors by the ratio of the mean flows to ensure the correct mean generation from the combined flow. Flow set: *Tek_Puk* (Total inflows to both lakes) – this is a modelled natural series
2. Two-lake simulation of Tekapo-Pukaki system (i.e. separate Tekapo simulation). Lake Tekapo treated separately with a stand-alone Tideda simulation of its operation. This accounts for bottleneck effect of the canal. Flow sets: Tekapo (trib), Pukaki (including Tekapo outflow. '*Pukaki'* is a hypothetical actual flow, not a natural flow series; and
3. Natural Inflows to each lake separately. Flow sets: Nat_tek and *Nat_puk*.. Natural inflows to Lake Tekapo are also actual flows. Natural inflows to Lake Pukaki is a simulated natural series.

3.2.2 Manapouri natural local inflows

The HMD Manapouri data is intended to be used as a tributary flow, whereas Te Anau is a controllable flow. 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 Apr 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 Aug 1969. Outflow was first measured downstream of the Mararoa confluence (with power station flows added) (Duffy et al, October 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 (April 1989) and later confirmed by Maslin et al (February 1993).

Several options are available for the local Manapouri flows (one of these is a modelled ‘natural’ flow):

1. With Mararoa diversion (Manawmara). Note that when Mararoa flows are above $40m^3/s$, 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.
2. Without Mararoa (*Manapouri*), which represents the view of a possible extreme outcome of water rights application. This is a hypothetical natural flow; and
3. With the minimum flow regime implemented and Mararoa dirty water spill (Manareduced). This is hypothetical actual flow.

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