REPORT

Flow Naturalisation for Six Hawke's Bay River Catchments:

Tutaekuri, Waipawa, Tukipo, Tukituki, Maraetotara and Porangahau

Prepared for Hawke's Bay Regional Council

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1	10/2011	Final Report			
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Executive Summary

This investigation is part of the Hawke's Bay Regional Council's (HBRC) programme for the management of the region's water resources.

In many of the Region's catchments the river flows we see are not natural but are influenced by pressures such as abstraction, diversion, dams and urbanisation. To gain an appreciation of the true nature of a river's resource it is necessary to determine what the river flow would have been like without any abstractions or discharges of water, i.e. the ***naturalised flow***.

Naturalised flow records are vital in assessing the nature of the water resource and to what extent water may be allocated for use from it.

MWH has been commissioned to carry out desktop hydrological investigations to develop and update naturalised flow datasets for seven river sites in the Hawke's Bay region:

- Tutaekuri River at Puketapu
- Waipawa River at RDS
- Tukipo River at SH50
- Tukituki River at Tapairu Rd
- Tukituki River at Red Bridge
- Maraetotara River at Te Awanga
- Porangahau River at below Mangaorapa

Analyses of recorded flow data, metered abstraction data and resource consent records have been carried out in the river flow naturalisation process. The process is dependent on the availability of good quality data for both the river flow and all abstractions.

The methodology adopted for this investigation consists of five key steps for each site:

1. Derive a dataset of average daily flow at the flow monitoring site
2. Analysis of resource consent records to derive the average daily consented allocation for all landuses for each irrigation season
3. Compare metered abstraction data to the consented allocation rates for the meter site and derive the percentage actual water use for those abstractions
4. Apply the percentage actual water use (Step 3) to the average daily allocation of **all** consent records (Step 2) in the catchment to produce the estimated actual daily average abstraction
5. Add to the average daily river flow data to derive a **naturalised flow dataset**.

Table E-1 details the estimated percentage actual water use for the three main catchments in Hawke's Bay for each month of the irrigation season running from October to May inclusive.

Table E-1: Estimated Percentage Actual Water Use by Catchment and Irrigation Month

Month	Tutaekuri	Ngaruroro	Tukituki
October	4	6	11
November	17	14	19
December	15	12	23
January	26	16	29
February	8	15	29
March	4	10	20
April	2	4	11
May	0	1	4
Irrigation Season Average	**9**	**10**	**18**

Further analysis shows variation between different landuse types in the amount of water abstracted. Table E-2 shows that cropping landuses account for the smallest percentage (6%) of allocated water. Residential use shows the greatest percentage, but of the irrigation uses the highest use is by orchard (15%). Peak use is by orchard irrigation in January.

Table E-2: Metered Actual Water Use as Percentage of Allocation - by Landuse Type

Month	Pastoral Farming	Cropping	Orchard	Vineyard	Residential	AVERAGE
October	8	2	3	7	14	6
November	17	8	23	16	21	17
December	17	8	18	16	16	15
January	24	10	37	18	23	22
February	21	11	21	16	17	17
March	17	6	10	9	17	12
April	9	2	4	4	15	7
May	1	0	0	2	7	1
Irrigation Season Average	**14**	**6**	**15**	**11**	**16**	**12**

The naturalised flow datasets that have been created for each river site can be added to the HBRC hydrological database.

Metering of water abstractions has been invaluable in this study and will be of great benefit in further defining the state of region's water resource. As such, HBRC should continue to encourage the collection of water abstraction data as well as encouraging meter readers to consistently take readings.

HAWKE'S BAY REGIONAL COUNCIL

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1 Introduction

This study is part of the Hawke's Bay Regional Council's (HBRC) commitment to the management of the region's water resources.

MWH has been commissioned to carry out desktop hydrological investigations to develop naturalised river flow datasets at seven specified sites in the Hawke's Bay region. Analysis of recorded flow data, metered abstraction data and resource consent records have been used in the naturalisation process.

These days many catchments are 'managed'. The river flows we see are not natural but are influenced by pressures such as abstraction (e.g. irrigation, water supply), diversion, dams and urbanisation. To gain an appreciation of the true nature of a river's resource it is necessary to determine what the river flow would have been like with no abstractions or discharges of water, i.e. naturalised flow.

Essentially flow naturalisation involves taking the measured river flow and adding back in all the upstream abstractions. The naturalisation of a river flow is critically dependent on the availability of good quality data for both the river flow and all abstractions.

Naturalised flow records are vital in assessing the nature of the surface water resource and to what extent water may be allocated for use from it.

1.1 Background

Naturalised flow records for six Hawke's Bay rivers were derived in *Flow Naturalisation for Six Hawke's Bay Rivers* (Opus 1997). The available data at the time was used to estimate the amount of actual water abstracted from rivers allowing naturalised flow records to be created for the period 1969 to 1996. The sites for which naturalised flow data were derived were:

- Tutaekuri River at Puketapu
- Ngaruroro River at Fernhill
- Waipawa River at RDS
- Tukipo River at SH50
- Tukituki River at Tapairu Rd
- Maraetotara River at Waimarama Rd

Since the 1997 work there has been a significant increase in the amount of water allocated for abstraction from these catchments and Hawke's Bay surface water resources in general. Knowledge on how much water is actually used has improved over time and it is now logical to update and revise the naturalised flow records so that HBRC can more effectively carry out its water management functions.

MWH (2009) extended the Opus (1997) naturalised datasets from 1996 to 2008 using actual water use data to estimate the amount abstracted from each river. The estimates of water use are considered more accurate than those used by Opus.

MWH (2010) revised and updated the naturalised flow data for the Ngaruroro River at Fernhill only. The MWH (2009) water use results and methods were adopted to re-create the previous 1969 to 1996 dataset. A total naturalised flow dataset for the Ngaruroro River at Fernhill was developed using the latest water use results.

This current investigation uses the MWH (2009) methods to update the 1969 to 1996 data and develop complete naturalised flow datasets from 1969 to 2008.

1.2 Objectives

The objective of this study is to provide HBRC with naturalised daily flow data for seven river sites:

- Tutaekuri River at Puketapu
- Waipawa River at RDS
- Tukipo River at SH50
- Tukituki River at Tapairu Rd
- Tukituki River at Red Bridge
- Maraetotara River at Te Awanga
- Porangahau River at below Mangaorapa

The Porangahau River is the only site not to have had previous flow extension/naturalisation work carried out.

The locations of these sites are shown in Figure 1-1. HBRC has supplied relevant hydrological data, consent supporting information and metered abstraction data. This report details the methodologies followed and analyses performed to derive the naturalised data.

Synthetic flow data has been created for some sites to obtain datasets extending back to at least 1969.

The irrigation season is defined as October to May (inclusive) for this investigation. MWH (2009) previously used November to April as the irrigation seasons. However, HBRC now considers October to May to be more representative of the period that water is used for irrigation.

Accordingly, as well as using this irrigation season to recreate the 1969 to 1996 naturalised flows, the MWH (2009) naturalised flow data from 1996 to 2008 is updated to reflect this season definition.

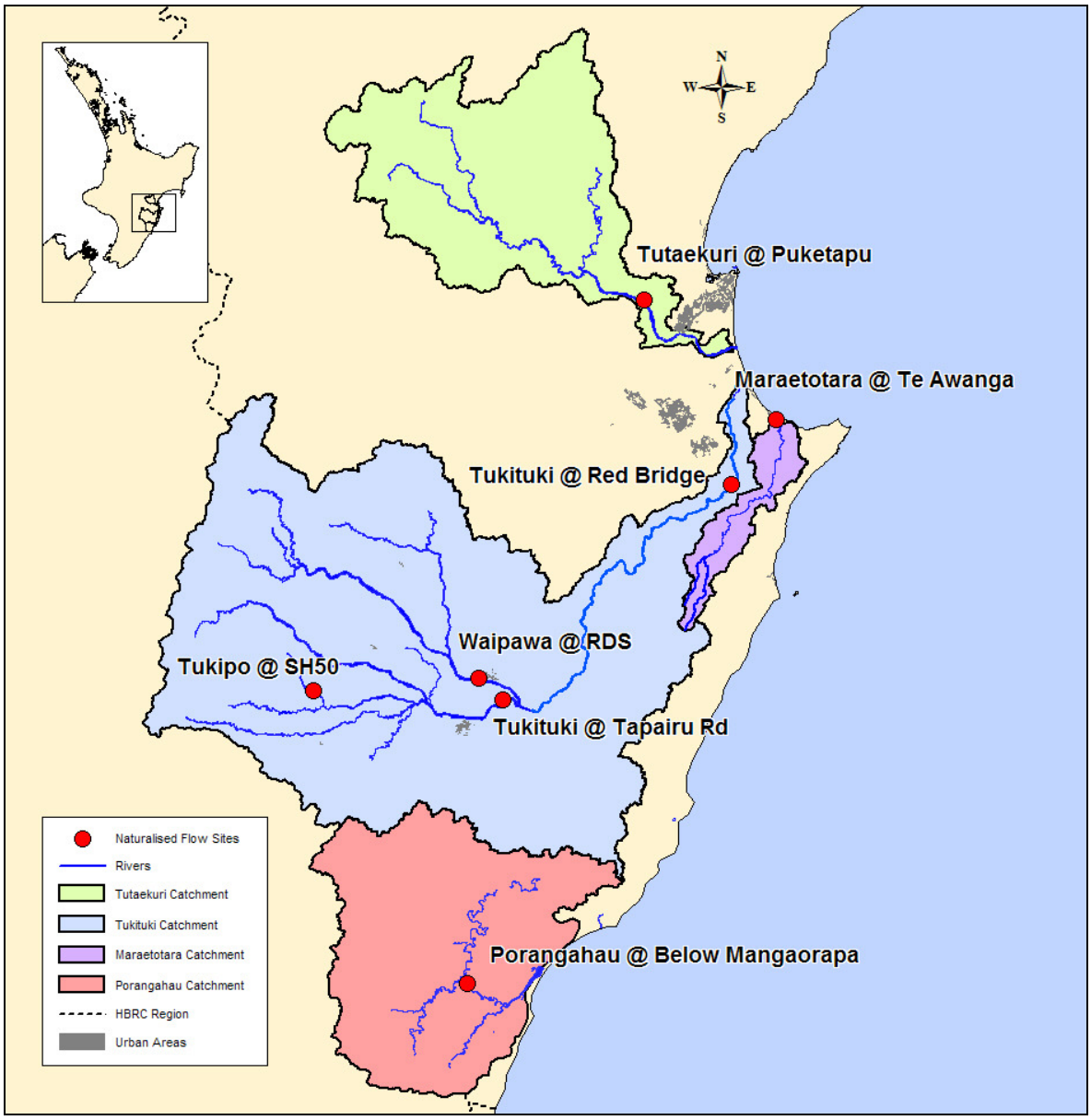

Figure 1-1: Hawke's Bay Naturalised River Flow Sites

2 Data

Data and information used in this study have been collected from a number of sources:

- Hydrological data from the HBRC Environmental Monitoring Database
- Hydrological data from the Horizons Regional Council Hydrometric Archive
- Hydrological data from NIWA
- Climate data from the National Climate Database (operated by NIWA) via the CliFlo web-based system
- Resource consent information from the HBRC consents database
- Previous hydrological, water resource and water management reports (see Bibliography for details)
- Local knowledge from HBRC staff

2.1 Hydrological Data

The flow data used in this study are detailed in Table 2-1. In addition to recorded data collected by HBRC, Horizons and NIWA, naturalised flow data created by MWH (2009) and Opus (1997) were used.

Flow gauging data, particularly concurrent flow gauging information, were also supplied by HBRC for many sites within the study catchments.

Table 2-1: River Flow Recorders

Site No.	Site Name	Period	Easting	Northing	Recording Authority
23047	Tutaekuri River at Ngaroto Rd	1991-2008	2821900	6188800	HBRC
23001	(i) Tutaekuri River at Puketapu (ii) Tutaekuri River at Puketapu (Naturalised)	1968-2008 1969-1996	2835723	6181216	HBRC
23209	Otane Stream at Glendon	1964-2008	2816652	6140596	NIWA
23235	(i) Waipawa River at RDS (ii) Waipawa River at RDS (Naturalised)	1988-2008 1969-1996	2815300	6133900	HBRC
23220	(i) Tukipo River at SH50 (ii) Tukipo River at SH50 (Naturalised)	1976-2008 1969-1996	2794800	6132400	HBRC
23207	(i) Tukituki River at Tapairu Rd (ii) Tukituki River at Tapairu Rd (Naturalised)	1987-2008 1969-1996	2818300	6131200	HBRC
23201	Tukituki River at Red Bridge	1968-2008	2846597	6158135	NIWA
23302	(i) Maraetotara River at Waimarama Rd (ii) Maraetotara River at Waimarama Rd (Naturalised)	1991-2008 1969-1996	2848700	6156100	HBRC
24325	Porangahau River at Wallingford	1980-2010	2815600	6104800	HBRC
24304	Mangaorapa Stream at Mangaorapa Rd	2000-2010	2812300	6095300	HBRC
25003	Akitio River at Weber	1979-2001	2791889	6083211	Horizons

2.2 Consent Data

Details of all resource consents for surface water abstraction from the study catchments have been supplied by the HBRC consents department. The data was supplied, up to the end of the 2008 irrigation season, in spreadsheet format detailing the abstraction, location, allocation amount, landuse type (e.g. cropping, vineyard, water supply etc), commencement and expiry date.

2.3 Meter Data

A database of metered abstraction data is maintained by HBRC. Abstraction data relevant to study areas was analysed by MWH (2009) to derive total catchment abstraction amounts.

Table 2-2 details the number of available metered abstraction data records. Data up to the end of the 2008 irrigation season has been used.

The period of records are generally quite short and the data quality can be poor in some instances, but it does provide a relative picture of the actual abstractive use of the water resource in comparison to the amount allocated by resource consent.

Table 2-2: HBRC Relevant Metered Surface Water Abstraction Data

	Meter Data Sites		**Suitable Meter Data by Landuse**				
Catchment	Total Sites	No. of Sites Suitable for Analysis	Pastoral Farming	Cropping	Orchard	Vineyard	Other
Tutaekuri	30	13	3	3	3	4	0
Ngaruroro	92	44	14	9	3	18	0
Tukituki	59	18	8	4	1	1	4
Maraetotara	3	1	1	0	0	0	2

3 Actual Water Use versus Allocation

A number of investigations throughout Hawke's Bay and New Zealand have made estimates of the amount of water actually abstracted for use in comparison to the amount available through allocation.

MWH (2009) summarises the estimates. Results relevant to the Hawke's Bay region are presented here.

3.1 Previous Hawke's Bay Investigations

Opus (1997) presented results of three surveys conducted by HBRC into water use in the Ngaruroro, Tutaekuri and Central Hawke's Bay catchment areas.

The conclusions reached were that 40% of the total allocation was actually abstracted from the Ngaruroro catchment; 17% of the total allocation was abstracted from the Tutaekuri catchment; and less than half of the total allocation was abstracted in the Tukituki catchment (including the Tukipo and Waipawa rivers).

The HBRC *State of Our Environment 1998-2003* report (2004) presented water abstraction data for the Ngaruroro catchment between 1996 and 2003 showing that the maximum actual water use was 37% of the amount allocated. The average abstraction was 10%.

Two additional studies are contained in the Lincoln Environmental report *Information on Water Allocation in New Zealand* (2000) that show:

(i) actual use of Heretaunga Plains groundwater in the 1994/95 irrigation season was 23% of allocated volume
(ii) a survey of irrigators in 1994/95 estimated that 50% of the weekly allocation was used.

Table 3-1 summarises the above estimates of actual water use for the Hawke's Bay region

Table 3-1: Percentage Actual Water Use Summary

Source	Location	Percentage
HBRC (1997)	- Tutaekuri catchment	17
	- Ngaruroro catchment	40
	- Tukituki catchment	<50
HBRC (2004)	- Ngaruroro catchment	10
Lincoln (2000)	- Hawke's Bay	50
MWH (2009)	- Tutaekuri catchment	12
	- Ngaruroro catchment	12
	- Tukituki catchment	22

MWH (2009) analysed metered surface water abstraction data and compared it to the actual consented amount to obtain average actual abstraction rates by catchment, landuse, and month.

Table 3-2 details the results of the MWH (2009) analysis for the Tutaekuri, Ngaruroro and Tukituki catchments by monthly average and irrigation season average.

The season averages are less than those estimates in early investigations (Table 3-1).

Table 3-2: Metered Actual Water Use as Percentage of Allocation by Catchment

Month	Tutaekuri (2003-2008)	Ngaruroro (1996-2008)	Tukituki (2006-2008)
October	4	6	11
November	17	14	19
December	15	12	23
January	26	16	29
February	8	15	29
March	4	10	20
April	2	4	11
May	0	1	4
Irrigation Season Average	**9**	**10**	**18**

Table 3-3 details the MWH (2009) results of actual water use by landuse type.

Table 3-3: Metered Actual Water Use as Percentage of Allocation - by Landuse Type

Month	Pastoral Farming	Cropping	Orchard	Vineyard	Residential	AVERAGE
October	8	2	3	7	14	6
November	17	8	23	16	21	17
December	17	8	18	16	16	15
January	24	10	37	18	23	22
February	21	11	21	16	17	17
March	17	6	10	9	17	12
April	9	2	4	4	15	7
May	1	0	0	2	7	1
Irrigation Season Average	**14**	**6**	**15**	**11**	**16**	**12**

The issued resource consent at each of the metered sites details the landuse that the water is used for.

4 Methodology

Deriving a naturalised flow record consists of three basic steps:

- Convert recorded flow data to average daily flow
- Use recorded abstraction data and consent records to estimate actual abstraction rates
- Add the estimated abstraction rates to the daily flow record to derive a naturalised flow dataset

Table 4-1 breaks these basic steps down into a more detailed methodology followed in this investigation to derive naturalised flow records for each of the seven sites.

Table 4-1: Flow Naturalisation Methodology

1	**River Flow**
1.1	Derive ***Average Daily Flow*** for the minimum flow monitoring site: • Check recorded flow data • Fill any gaps with data derived from nearby sites
2	**Consented Allocation**
2.1	Collate all consented surface water abstractions in each catchment from consent records/database (HBRC classify abstractions from groundwater that are within 400m of a surface water body as surface water takes): • Divide into annual irrigation seasons (e.g. 2002/03) • Calculate total weekly consented ***Allocation Volume*** per irrigation season
2.2	The ***Allocation Volume*** for each irrigation season is divided into landuse type (i.e. Pastoral Farming, Cropping, Orchard, Vineyard, Other)
2.3	Convert weekly ***Allocation Volume*** (per landuse) into average daily volume. Then convert to an average daily rate in litres per second. = ***Average Daily Allocation Rate*** for each landuse category.
3	**Metered Abstraction Data**
3.1	Collate ***Metered Abstraction Data*** in catchment (surface water takes only)
3.2	Use the ***Metered Abstraction Data*** and ***Allocation Volume*** to calculate the ***Percentage Actual Water Use*** for each metered abstraction per month of irrigation season (i.e. November to April)
3.3	Aggregate Step 3.2 by landuse type (from consent records) to derive a ***Percentage Actual Water Use*** for each landuse type
4	**Estimated Actual Water Use**
4.1	The ***Percentage Actual Water Use*** is applied to ***Average Daily Allocation Rate*** = ***Estimated Actual Daily Average Abstraction*** rate from the river (litres per second)
4.2	Use irrigation ban records to determine when abstractions banned or reduced
4.3	Revise ***Estimated Actual Daily Average Abstraction*** dataset if necessary in after Step 4.2
5	**Naturalised Flow Data**
5.1	Add the ***Estimated Actual Daily Average Abstraction*** to the ***Average Daily Flow*** = ***Naturalised Flow Dataset***

Sections 0 to 7 detail the process and results for each of the sites.

5 Tutaekuri at Puketapu

To derive a naturalised flow dataset for the Tutaekuri at Puketapu monitoring site the methodology detailed in Section 4 was followed.

Opus (1997) created a naturalised flow dataset for the Tutaekuri at Puketapu site from 1969 to 1996. The actual recorded flow data at the site was considered to be of poor quality and a synthetic flow record was derived using the nearby Esk River flow data.

The actual recorded flow data for the Tutaekuri at Puketapu was updated in subsequent years by HBRC, and MWH (2009) considered it to be of good quality and definitely more suitable than using that of a nearby catchment.

The 1997 investigation applied a blanket abstraction across the catchment – this being 17% of the amount of water allocated for the entire irrigation season. The results provided here supersede this method by deriving percentage estimates of the actual water used from metered data, classifying it by different landuse types and varying it over the irrigation season months (October to May).

5.1 Recorded Flow Data

There are a number of continuous river monitoring sites within the Tutaekuri. The key site in terms of this study is the Tutaekuri at Puketapu recorder, the same site for which the naturalised flow record is derived.

The Tutaekuri at Puketapu record is a combination of two sites. The original site (23001) operated between 1968 and 1978, while recording at the current site (23032) commenced at the closure of the original site in 1978. The two sites are approximately 30 m apart with no tributary inputs between.

A naturalised flow record for the Tutaekuri at Puketapu covering the period 1996 to 2008 has previously been derived (MWH 2009). Opus (1007) developed a naturalised flow record between 1969 and 1996 – which will be superseded by the results obtained in this investigation.

Opus (1997) considered the Tutaekuri at Puketapu data from 1969 to be of poor quality and subsequently derived a synthetic flow record for the site. The Tutaekuri at Puketapu recorded flow data has since been reviewed and updated by HBRC and is now of good quality and is used with confidence in this investigation.

5.2 Consented Abstractions

Records of consented surface water abstractions have been supplied by HBRC. Abstractions that are from a groundwater bore but within 400m of a surface water body are classed as surface water takes.

MWH (2009) analysed all consents and detailed the number of consents and amount of water allocated by irrigation season.

In the Tutaekuri catchment there is a noticeable increase in the allocation volume in 2002/03 and an even sharper increase from 2005/06 as shown in Figure 5-1. The maximum allocation (m^3/week) increased more than 300 percent between the 2003/04 and 2007/08 irrigation seasons.

The abstraction quantities range from 552 m^3/week to 32,825 m^3/week.

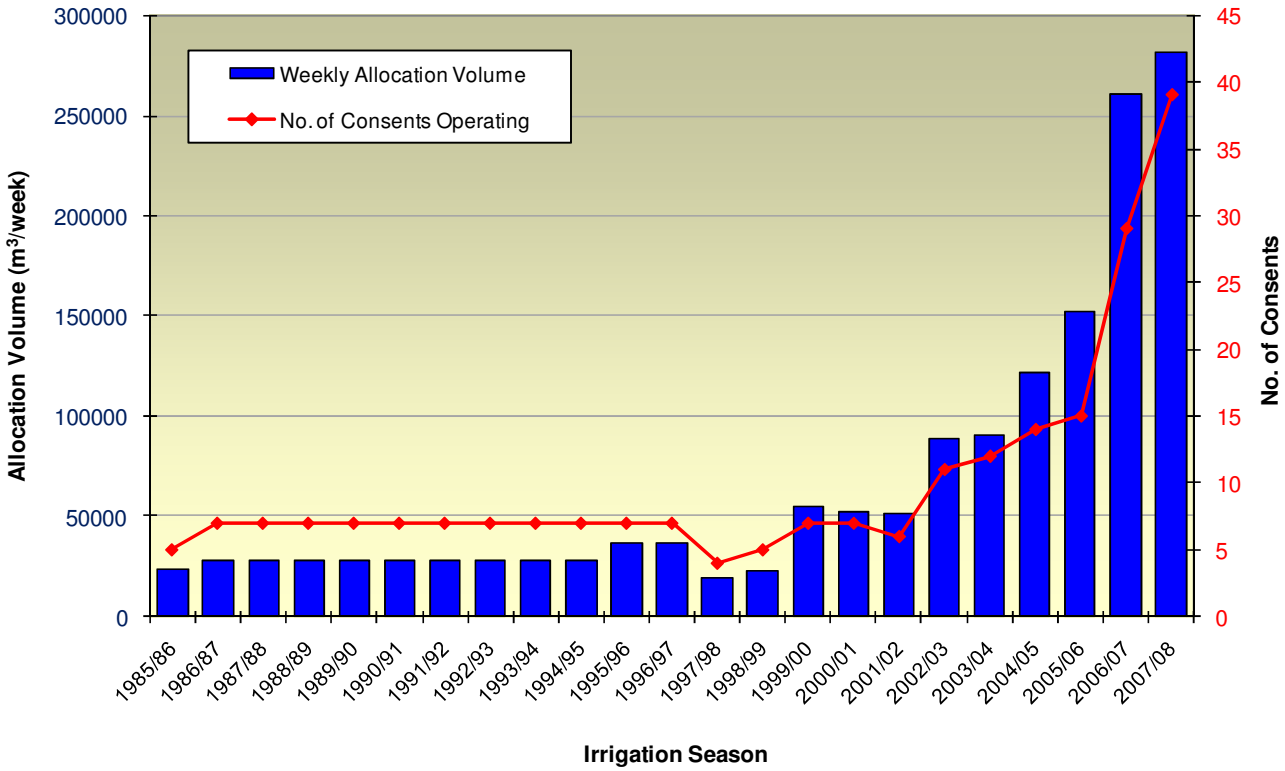

Figure 5-1: Tutaekuri Catchment - Trend in Consented Surface Water Abstractions

No details are available on abstraction permits prior to 1985.

The rates of abstraction from the Tutaekuri River for the 1985/86 season are low (see Figure 5-4) with a maximum of 9 L/s estimated as being abstracted in January.

Values this low fall within the margin of flow measurement error and it was decided to assume no consented abstraction prior to 1985/86.

5.3 Metered Actual Water Use

MWH (2009) analysed 13 metered surface water abstractions within the Tutaekuri catchment to determine the actual volume of water used for each metered consent and then compared to the actual allocated volume for that consent. This data is supplied to HBRC by the consent holder.

Metered abstraction data in the catchment is available from 2003.

5.3.1 Actual Use by Individual Meter

Figure 5-2 shows the actual water use as a percentage of allocation for the 13 Tutaekuri surface water abstraction sites that are metered.

The November to January months typically show the highest percentage of water use, although there is large variation between users. Only three of the users achieve more than 50% of their allocation (all in January).

Metered abstraction is at its lowest in May with only three of the metered sites using any water at very low rates.

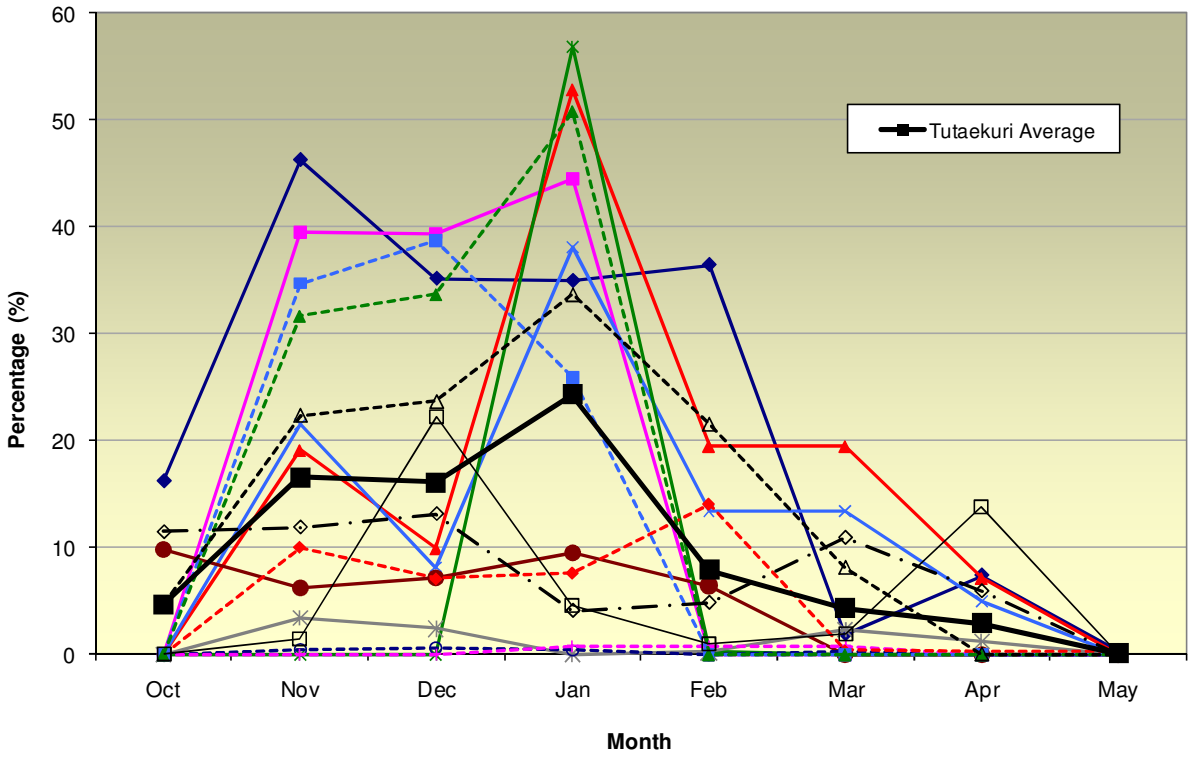

Figure 5-2: Tutaekuri Catchment Metered Surface Water Abstraction as a Percentage of Allocation

5.3.2 Actual Use by Landuse Type

The meter data has been divided up into the landuse category at each meter site. Figure 5-3 shows the variation of the percentage actual water use for the Tutaekuri catchment for the four landuse types of pastoral farming, cropping, vineyard and orchard. Vineyard and orchard abstractions typically use the greatest proportion in the November to January period.

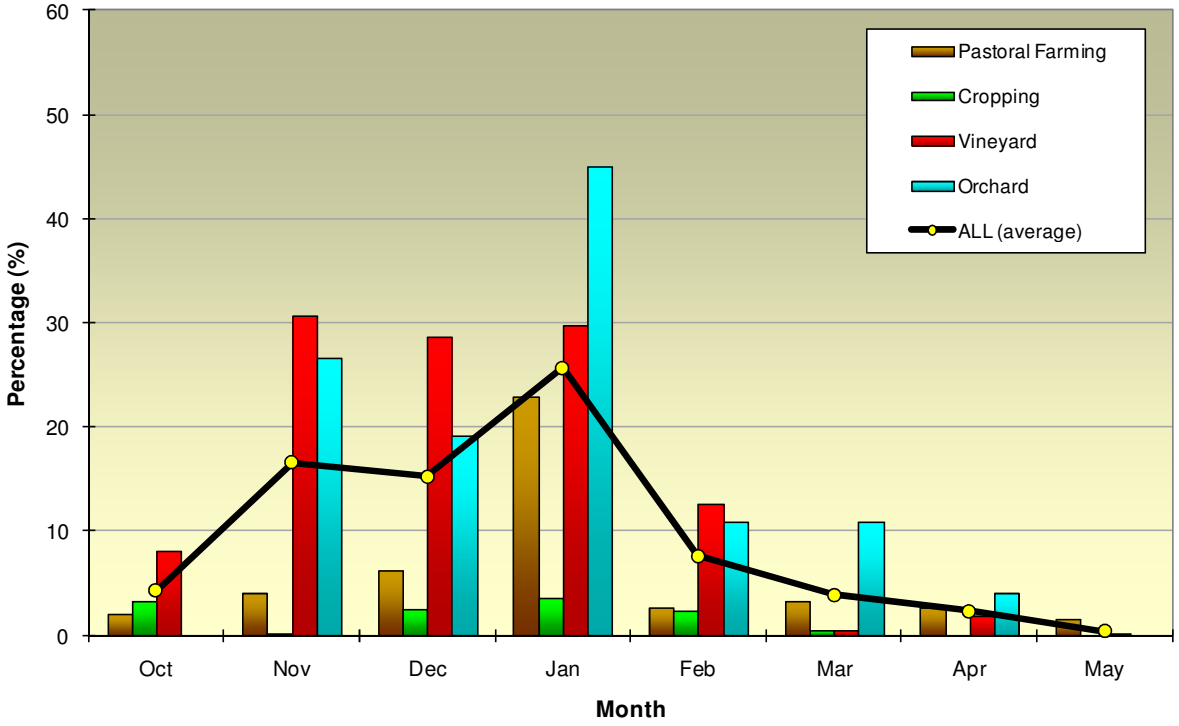

Figure 5-3: Tutaekuri Catchment Metered Data - Percentage Actual Water Use by Landuse Type

5.3.3 Estimated Total Actual Daily Abstraction

The metered abstraction data is used to estimate the total abstraction from the Tutaekuri River as described below. This is then applied to the recorded Tutaekuri River flow data to produce a naturalised flow record.

With only 13 metered abstraction takes in the Tutaekuri catchment (between 2003 and 2008) and all but one of these covering only a single irrigation season, the data has been combined with the neighbouring Ngaruroro catchment meter data to provide a larger dataset of 52 metered abstractions (MWH 2009).

The average percentage of actual use for each metered abstraction per month (October to May) is calculated and grouped together by landuse type as detailed in Table 5-1.

Table 5-1: Tutaekuri Catchment - Average Monthly Percentage Actual Water Use by Landuse Type

Month	Pastoral Farming	Cropping	Orchard	Vineyard		Average
October	7	3	5	6		5
November	16	7	22	15		15
December	13	6	19	15		13
January	21	6	34	18		20
February	14	7	18	15		13
March	11	3	12	9		9
April	5	1	5	4		4
May	1	0	0	2		1

All the consented surface water abstractions for the Tutaekuri catchment have been grouped on an irrigation season basis from 1969/70 to 2007/08. For each irrigation season the total allocated volume (m^3/week) is derived for five landuse categories:

- Pastoral farming
- Cropping
- Orchard
- Vineyard
- Other

Consented abstractions below the Tutaekuri at Puketapu flow recorder site are not included. Only those above the recorder are used so that the derived abstraction rates can be added to the recorded flow data to produce a naturalised flow record at the recorder site.

The total allocation volumes are divided further into total daily allocated volumes (m^3/day) per landuse, and then into an average daily abstraction rate in litres per second (L/s)

Figure 5-4 details the estimated actual average daily abstraction (L/s) for each month of each irrigation season. January has the highest water use rates, with use dropping away in March and April. There is minimal water use in May.

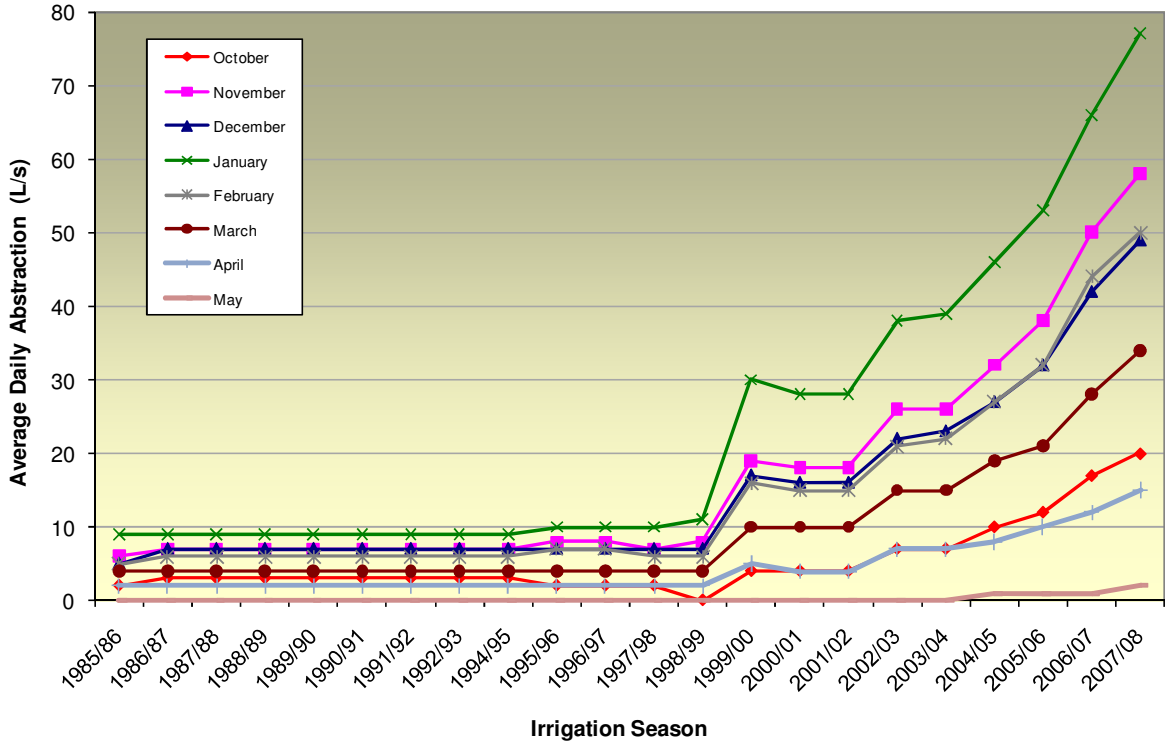

Figure 5-4: Tutaekuri River (above Puketapu) Trend of Estimated Average Daily Abstraction (L/s)

Irrigation ban records supplied by HBRC show no irrigation bans for the Tutaekuri River water users above the Puketapu minimum flow monitoring site.

A dataset of estimated average daily abstraction is compiled from 1969 to 2008 with no adjustments required for irrigation bans. This dataset is then used to naturalise the Tutaekuri River flow as detailed in Section 5.4.

5.4 Tutaekuri Naturalised River Flow

The methodology applied in this investigation (Table 4-1) has created two datasets from which the naturalised flow for the Tutaekuri River at Puketapu can be derived:

- Average Daily Flow (Section 5.1)
- Estimated Actual Daily Average Abstraction (Section 5.3.3)

A spreadsheet is used to add the abstraction data to the river flow and the resulting dataset represents the naturalised Tutaekuri at Puketapu flow record for the period 1 July 1969 to 30 June 2008.

Table 5-2 details flow statistics for the actual recorded flow and the naturalised flow data for the Tutaekuri River at Puketapu. All the tabled statistics are for daily flow.

The Q_{95} flow indicates the flow that is exceeded 95 percent of the time.

Table 5-2: Flow Statistics (L/s) for Naturalised and Actual Tutaekuri at Puketapu Flow (1969-2008)

	Mean	Median	Min	MALF	Q_{95}	Q_{90}	Q_{80}	Max
Naturalised Flow	14560	8591	1278	3641	3631	4284	5192	1067551
Actual Flow	14558	8590	1278	3636	3619	4275	5183	1067547

It is evident that the volume of abstraction from the Tutaekuri River has minimal effect on the low to median flow range. The naturalised daily median flow is 8591 L/s compared to the actual recorded daily median flow of 8569 L/s. The actual daily minimum flow of 1278 L/s is the same as the naturalised value.

The naturalised Q_{95} flow is 3 L/s greater than the actual Q_{95}.

6 Tukituki Catchment Sites

The Tukituki River catchment contains four flow sites that have been naturalised as part of this investigation:

- Tukipo at SH50
- Tukituki at Tapairu Rd
- Waipawa at RDS
- Tukituki at Red Bridge

These sites are also low flow monitoring sites for the minimum flow levels as defined in the RRMP (HBRC, 2006).

The methodology detailed in Section 4 was followed to derive naturalised flow records for these sites.

This investigation is able to apply actual estimates of the percentage of water used during the irrigation season according to landuse and the month (MWH 2009) rather than a constant 45% as applied by Opus (1997) for these catchments.

6.1 Recorded Flow Data

Table 6-1 details the main flow recording sites in the Tukituki catchment.

Flow data for the Tukipo at SH50, Tukituki at Tapairu Rd and Waipawa at RDS sites have previously been naturalised for the two periods; 1 July 1969 to 30 June 1996 (Opus 1997), and 1996 to 2008 (MWH 2009). Tukituki at Red Bridge only has naturalised flow from 1996 to 2008 (MWH 2009).

Table 6-1: Tukituki Catchment Flow Recorders

Site No.	River	Site Name	Period	Easting	Northing	Recording Authority
23209	Otane	Glendon	1964-2008	2816652	6140596	NIWA
23235	Waipawa	RDS RDS (Naturalised)	1988-2008 1969-1996	2815300	6133900	HBRC
1223220	Waipawa	Pendle Hill	1994-2008	2792400	6147100	HBRC
23220	Tukipo	SH50 SH50 (Naturalised)	1976-2008 1969-1996	2794800	6132400	HBRC
23203	Tukituki	Waipukurau SH2	1988-2008	2813765	6129060	HBRC
23207	Tukituki	Tapairu Rd Tapairu Rd (Naturalised)	1987-2008 1969-1996	2818300	6131200	HBRC
1223216	Tukituki	Shag Rock	1988-2008	2826410	6133095	HBRC
23201	Tukituki	Red Bridge Red Bridge (Naturalised)	1968-2008 1996-2008	2846597	6158135	NIWA

The early period of naturalised flow data (1969 to 1996) is updated and replaced in this investigation using the methods developed by MWH (2009). The 1996 to 2008 naturalised data is revised for the irrigation season of October to May (previous naturalised data used November to April).

The minimum flow for the Tukipo River at SH50 is stated as 150 L/s in the RRMP (HBRC 2006), however all operating consented abstractions (as at 2008) are linked to the former minimum flow of 100 L/s.

Similarly the Tukituki at Tapairu Rd site has a RRMP minimum flow of 1900 L/s but the consented abstractions are defined by the former minimum flow of 1600 L/s.

The RRMP sets minimum flows for Waipawa at RDS and Tukituki at Red Bridge as 2300 L/s and 3500 L/s respectively. Consented abstractions linked to the Waipawa at RDS site have additional flow levels at 3400 L/s and 4000 L/s when certain abstractions must cease.

Restrictions on abstractions are also linked to a flow of 4000 L/s as measured in the Tukituki River at Patangata for some consent holders.

6.2 Consented Abstractions

Consent records of surface water abstractions have been supplied by HBRC. Sections 6.2.1 to 6.2.5 detail the consents relevant to each of the flow recorder sites.

Detailed summaries of the consent information are provided by MWH (2009).

6.2.1 Tukipo Consented Abstractions

Table 6-2 summarises the consents for the Tukipo catchment.

The earliest records show one consent operating in the 1991/92 irrigation season. From 1992/93 to the 2007/08 season five consents for water abstraction have been operating for a total allocated weekly volume of 31,618 m^3.

In the subsequent flow naturalisation process (Section 6.4) it is assumed that for the years 1969-1991 the same amount of water is allocated as for the 1991/92 season.

Table 6-2: Tukipo Catchment Consented Surface Water Abstractions

Irrigation Season	No. of Surface Water Abstraction Consents	Maximum Allocation (m^3/week) above Tukipo at SH50
1991/1992	1	12,000
1992/1993 to 2007/2008	5	31,618

The size of the water abstraction takes range from 605 m^3/week to 13,000 m^3/week.

6.2.2 Tukituki at Tapairu Rd Consented Abstractions

Figure 6-1 details the surface water abstraction consents for the Tukituki catchment above Tapairu Rd, but not including those relating to Tukipo at SH50 as detailed in Section 6.2.1.

There are noticeable increases in the allocation volume in 1992/93 and 2000/01.

The size of the water abstraction takes range from 325 m^3/week to 66,500 m^3/week.

Records show three consents operating in the 1991/92 irrigation season. A sharp rise to 35 abstraction consents in 1992/93 was been followed by a steady rate of increase to 48 consents in 2002/03.

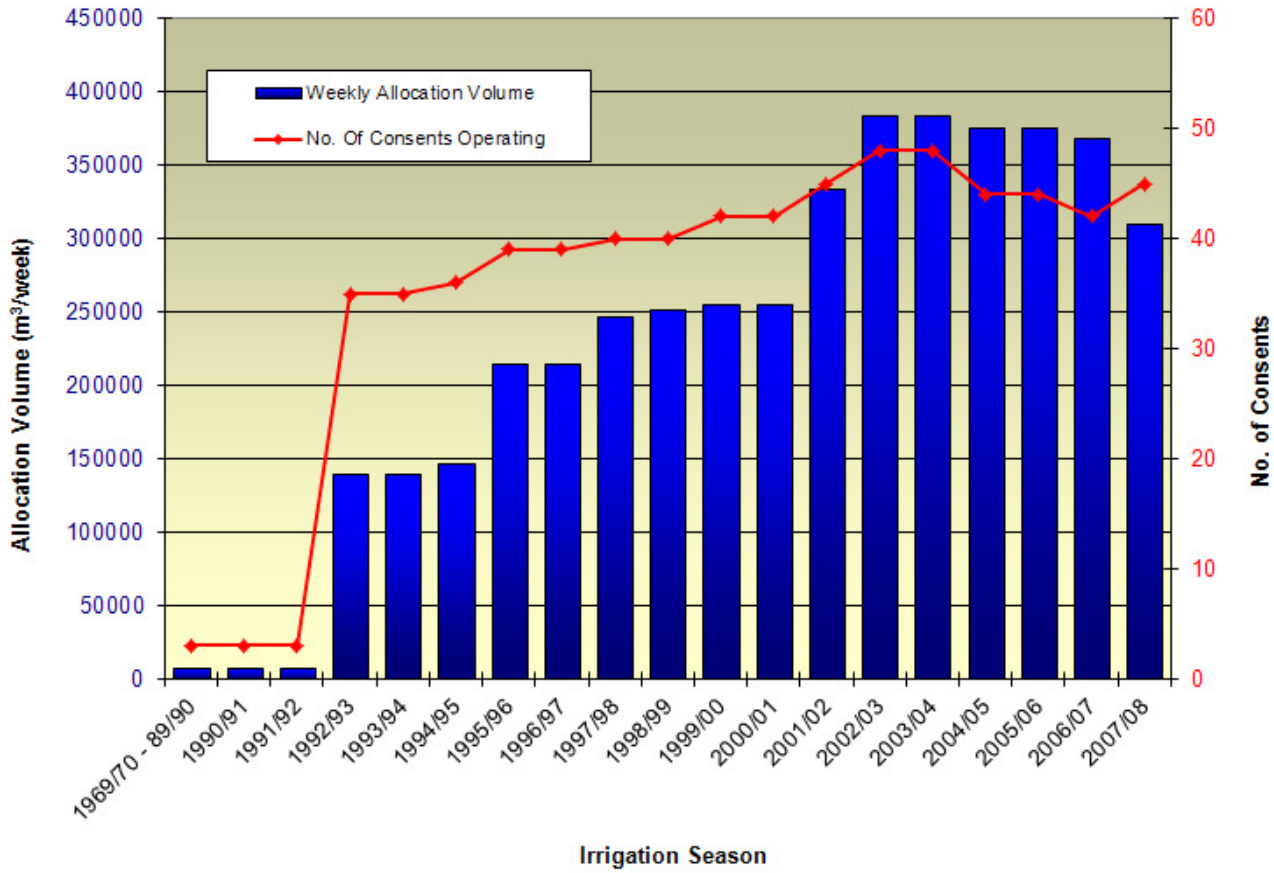

Figure 6-1: Tukituki at Tapairu Rd - Trend in Consented Surface Water Abstractions

The amount of consented allocation in the 1991/92 season (earliest records) is assumed for all earlier seasons from 1969/70.

6.2.3 Waipawa at RDS Consented Abstractions

Figure 6-2 summarises the surface water abstraction consents for the Waipawa catchment above RDS. There is a noticeable increase in the allocation volume in 1994/95. Since then the weekly allocation volume has ranged between approximately 250,000 m^3 and 350,000 m^3.

The earliest records show one consent in the 1990/91 and 1991/92 irrigation seasons. This increased to 22 abstraction consents in the 2006/07 irrigation season.

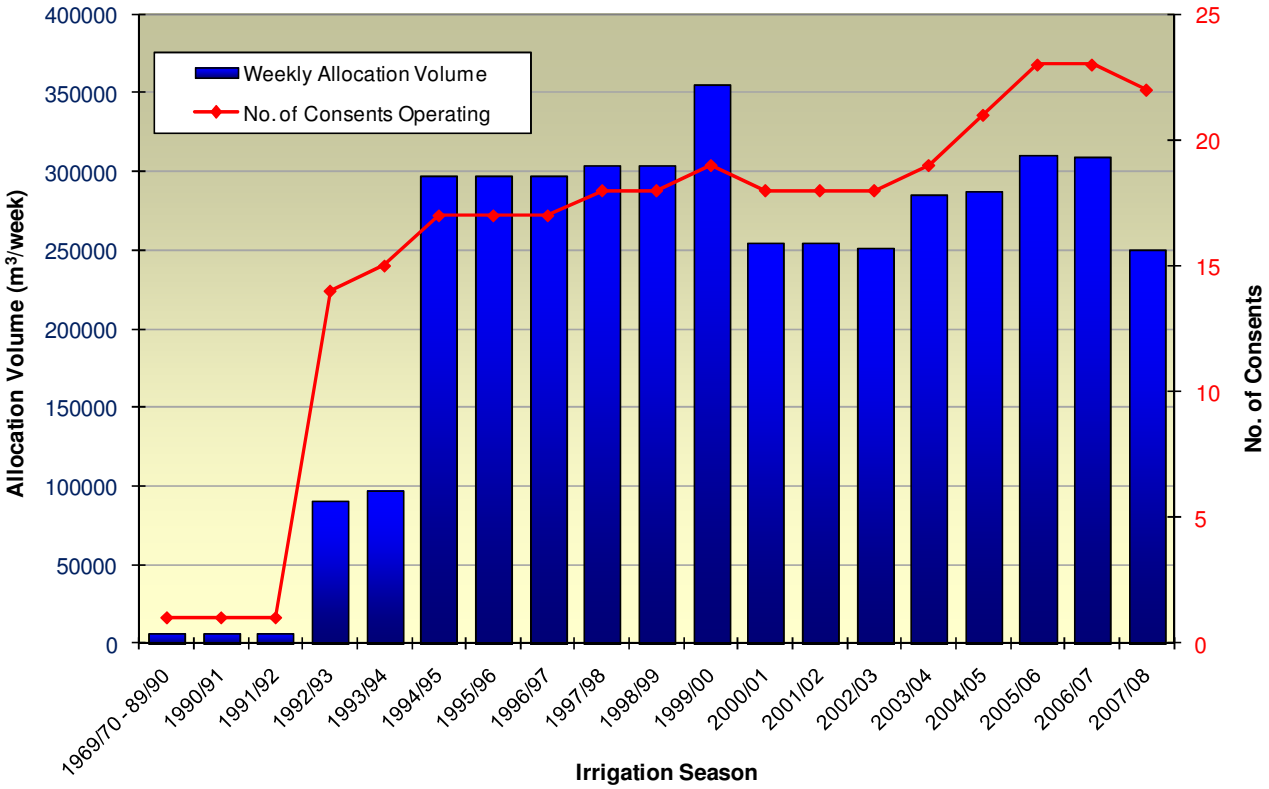

Figure 6-2: Waipawa at RDS - Trend in Consented Surface Water Abstractions

The amount of consented allocation in the 1990/91 season (earliest records) is assumed for all earlier seasons from 1969/70.

6.2.4 Tukituki at Red Bridge Consented Abstractions

Figure 6-3 summarises the surface water abstraction consents over time for the catchment area above the Tukituki at Red Bridge site but not those relating to the Tukipo at SH50 (Section 6.2.1), Waipawa at RDS (Section 6.2.2), and Tukituki at Tapairu Rd (Section 6.2.3) sites.

There is a steady increase in the allocation volume over time peaking at 266,246 m^3/week in 2007/08.

Records show 11 consents operating in the 1992/93 irrigation season. The 2007/08 irrigation season had 28 abstraction consents.

The size of individual consented water abstraction takes range from 308 m^3/week to 38,500 m^3/week.

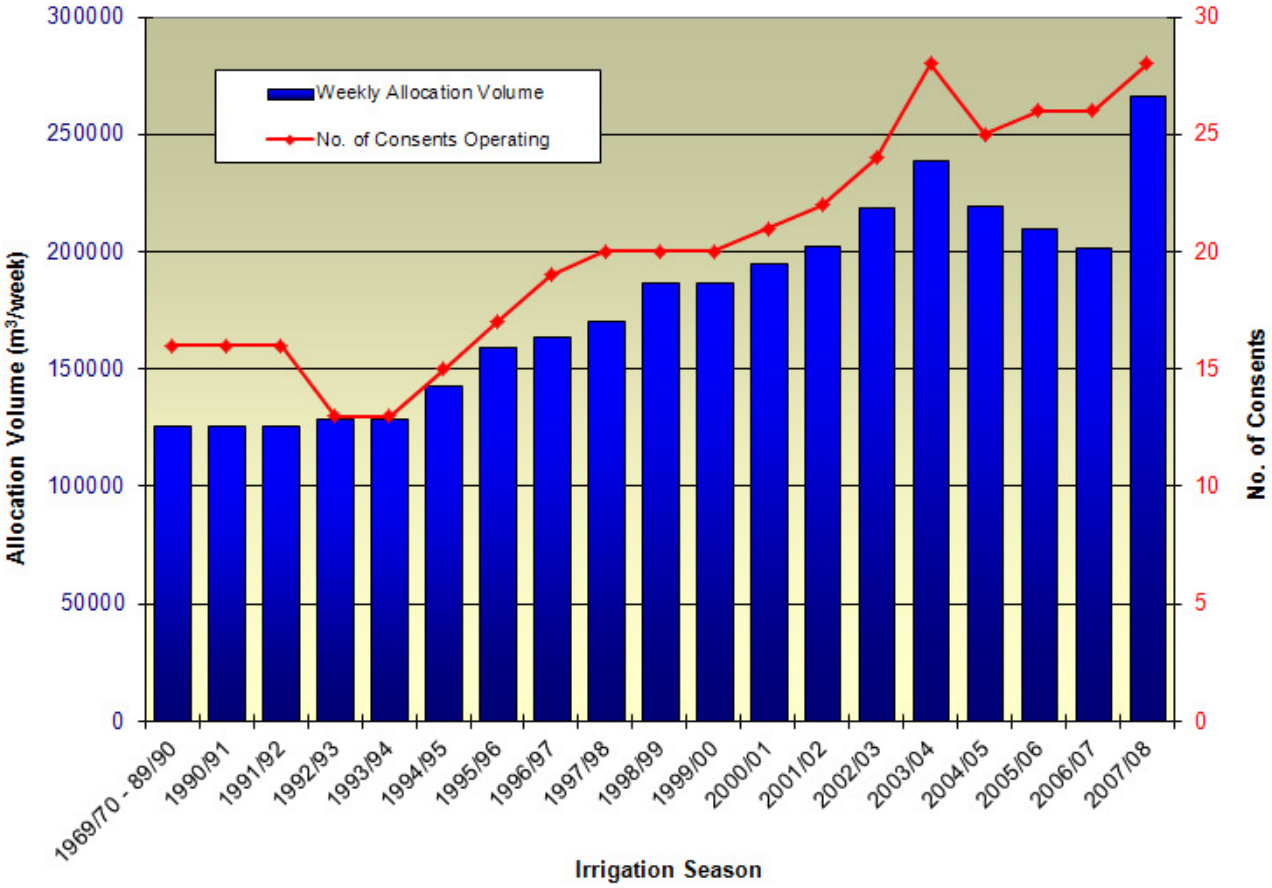

Figure 6-3: Tukituki at Red Bridge - Trend in Consented Surface Water Abstractions

The amount of consented allocation in the 1990/91 season (earliest records) is assumed for all earlier seasons from 1969/70.

6.2.5 Tukituki below Red Bridge Consented Abstractions

Figure 6-4 summarises the surface water abstraction consents over for the Tukituki River catchment below the Red Bridge recorder site. There is a noticeable increase in the allocation volume in 2002/03 when the number of consents increases from 2 to 12.

The earliest records show one consent operating from the 1990/91 irrigation season up until the 2001/02 season. There were 16 abstraction consents in the 2007/08 irrigation season.

The size of individual consented water abstraction takes range from 140 m^3/week to 9,834 m^3/week.

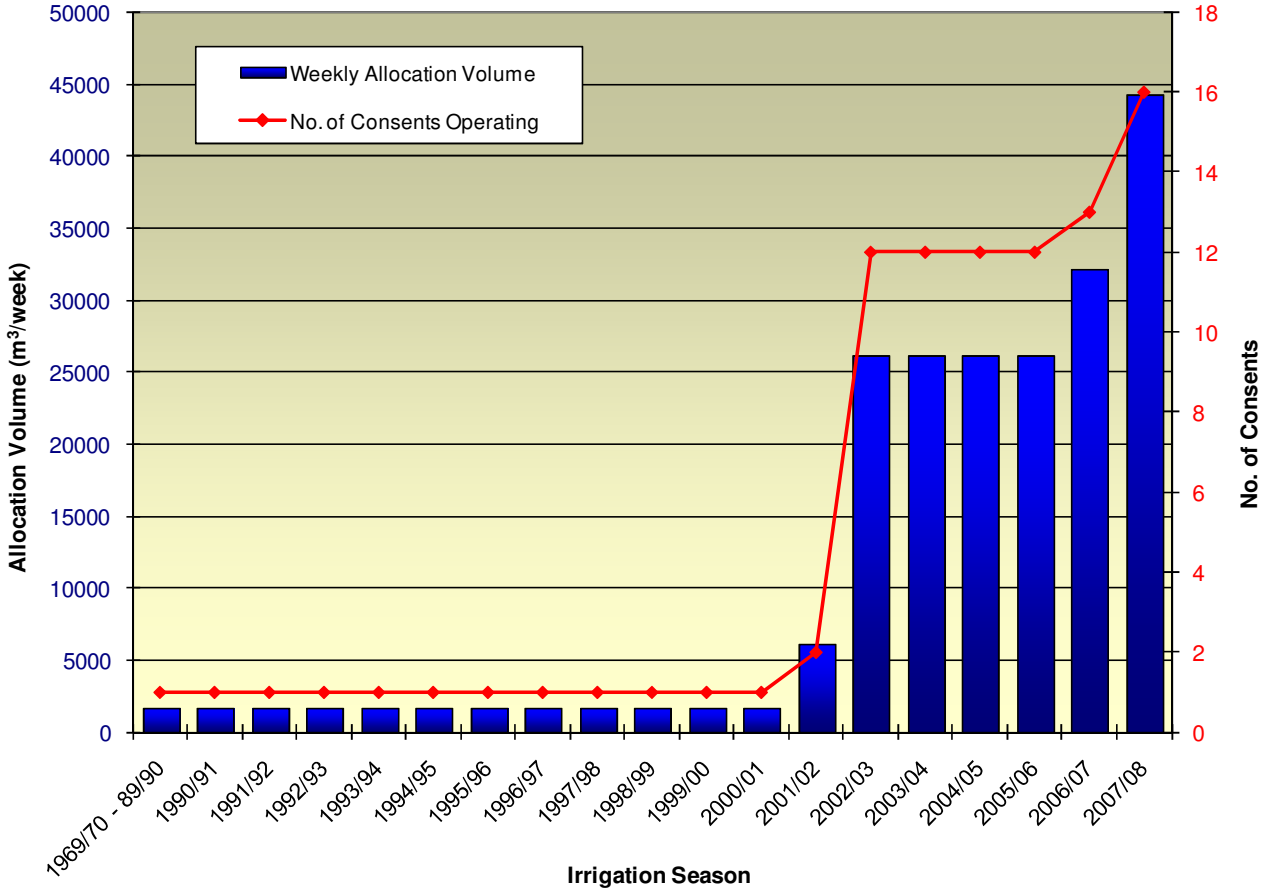

Figure 6-4: Tukituki below Red Bridge - Trend in Consented Surface Water Abstractions

6.2.6 Tukituki Catchment Consented Abstractions Summary

Figure 6-5 presents a summary of all surface water abstraction consents over the whole of the Tukituki catchment.

There has been a steady increase in the number, and total allocation volumes, of consents since 1992/93.

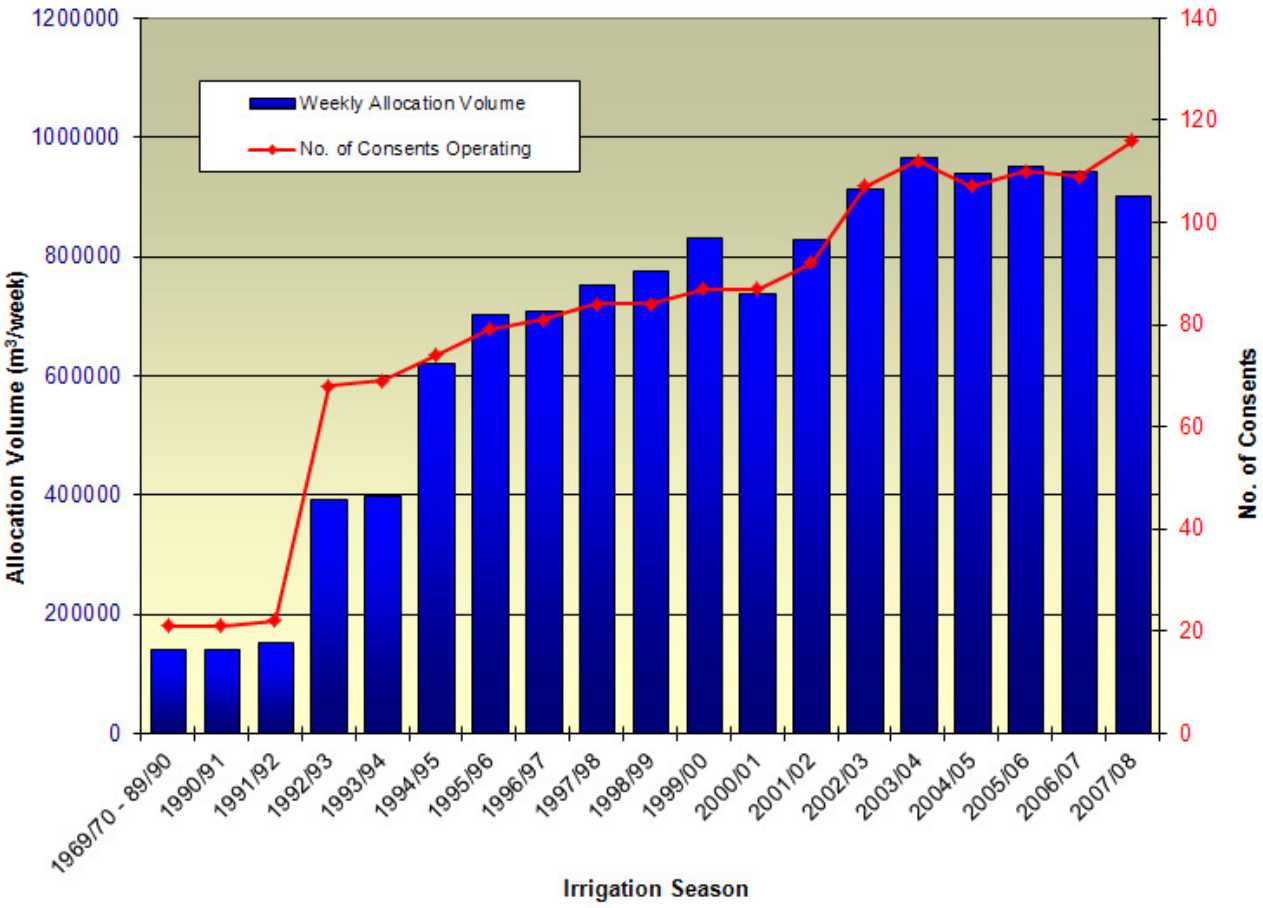

Figure 6-5: Entire Tukituki Catchment - Trend in Consented Surface Water Abstractions

6.3 Metered Actual Water Use

MWH (2009) presented analyses of metered surface water abstractions in the Tukituki catchment to determine the actual volume of water used for each metered consent and then compared to the actual allocated volume for that consent.

6.3.1 Actual Use by Individual Meter

Figure 6-6 shows the actual water use as a percentage of allocation for the Tukituki catchment meter sites.

The January and February months show the highest overall percentage of water use. There is wide variation between users over the irrigation season.

Six of the consent holders use more than 50% of their allocation in any month. The maximum monthly usage for each site ranges from less than 1% to 97%.

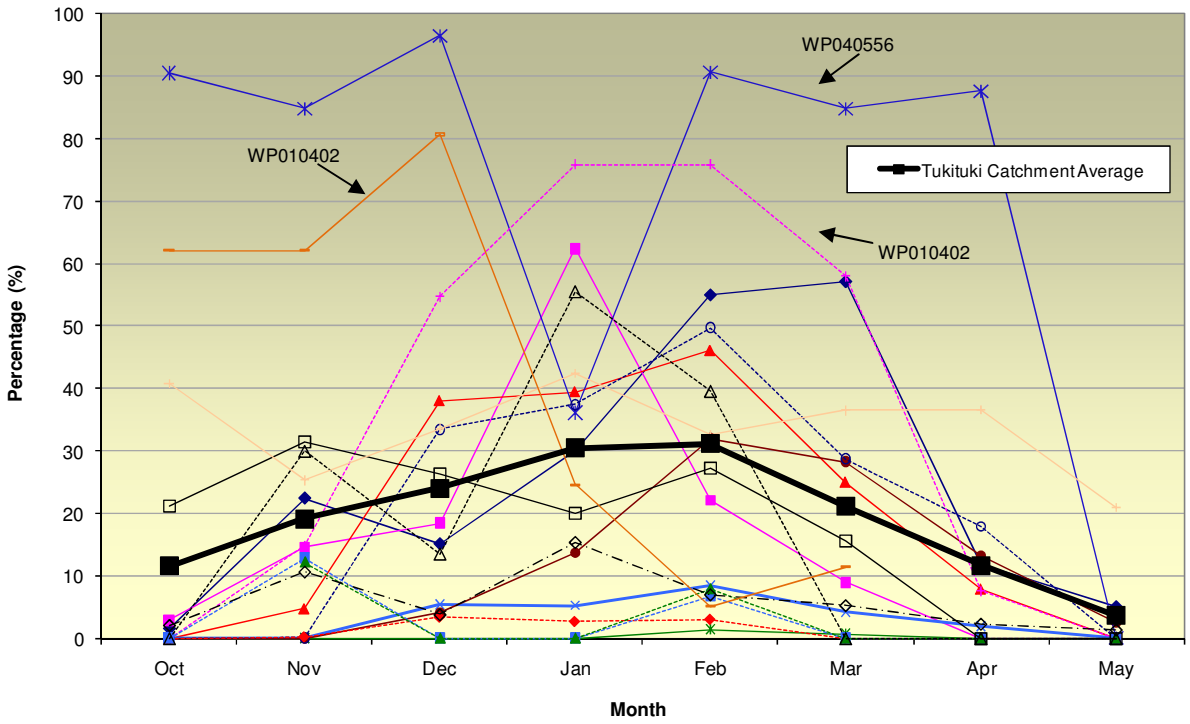

Figure 6-6: Tukituki Catchment Metered Surface Water Abstraction as a Percentage of Allocation

6.3.2 Actual Use by Landuse Type

The meter data has been divided up into the landuse category at each meter site. Figure 6-7 shows the variation of the percentage actual water use for the Tukituki catchment for the four landuse types of pastoral farming, cropping, vineyard and orchard.

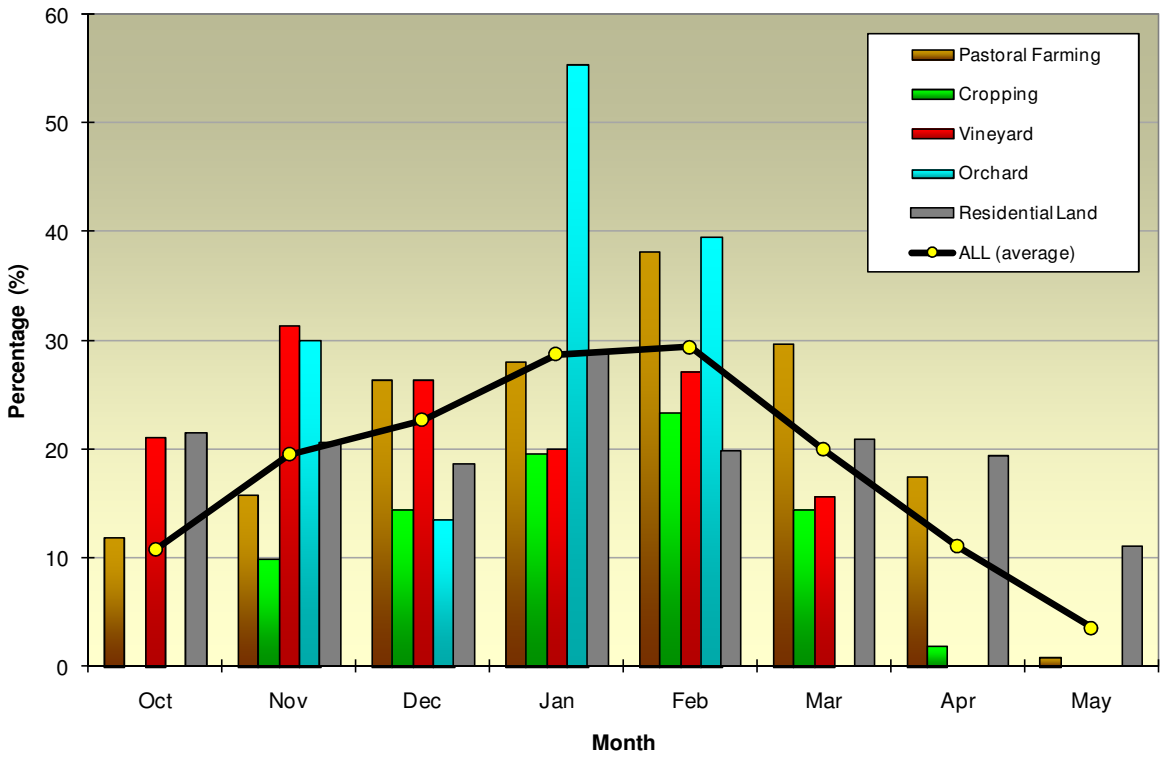

Figure 6-7: Tukituki Catchment Metered Data - Percentage Actual Water Use by Landuse Types

The orchard and vineyard figures are based on only one meter for each.

6.3.3 Estimated Total Actual Daily Abstraction

The metered abstraction data is used to estimate the total abstraction from the Tukituki River. This is then applied to the four recorded flow data sites to produce naturalised flow records for each.

With there only being 18 metered abstraction takes in the Tukituki catchment, the data has been combined with the Ngaruroro catchment meter data (MWH 2009) to provide a larger dataset of 64 metered abstractions.

The average percentage of actual use for each metered abstraction per month (October to May) is calculated and collated by landuse type as presented in Table 6-3.

Table 6-3: Tukituki Average Monthly Percentage of Actual Water Use by Landuse Type

Month	Pastoral Farming	Cropping	Orchard	Vineyard	Other		Average
October	9	0	3	7	17		7
November	16	10	21	12	26		17
December	18	10	18	12	25		17
January	21	12	31	15	35		23
February	24	14	28	16	16		20
March	19	7	9	10	12		11
April	10	2	4	5	13		7
May	1	0	0	2	17		4

All the surface water abstraction consents for the Tukituki catchment have been grouped by irrigation season from 1969/70 to 2007/08 and then divided into catchment areas corresponding to each of the four flow recorder sites:

- Tukipo River at SH50
- Tukituki River at Tapairu Rd
- Waipawa River at RDS
- Tukituki River at Red Bridge

For each of the catchments and for each irrigation season the total allocated volume (m^3/week) has been derived for five landuse categories:

- Pastoral farming
- Cropping
- Orchard
- Vineyard
- Other

6.3.4 Estimated Actual Abstraction at Each Site

Consented abstractions above each site are used so that the derived abstraction rates can be added to the recorded flow data to produce a naturalised flow record at each recorder site.

The total allocation volumes (m^3/week) for each consented abstraction are divided into total daily allocated volumes (m^3/day) per landuse, and then into an average daily abstraction rate in litres per second (L/s).

The total actual daily abstraction above each of the sites has been derived by MWH (2009) for the 1996 to 2008 period. The analysis is extended to create records of total daily abstraction between 1969 and 2008 for each site.

Figure 6-8, Figure 6-9 and Figure 6-10 detail the trend of water use over time above the Tukituki at Tapairu Rd, Waipawa at RDS and Tukituki at Red Bridge sites.

February has the highest water use rates. A dataset of the average daily abstraction has been compiled from 1969 to 2008 for each site. Adjustments are made for periods of irrigation bans when abstractions would have ceased or been restricted (MWH 2009).

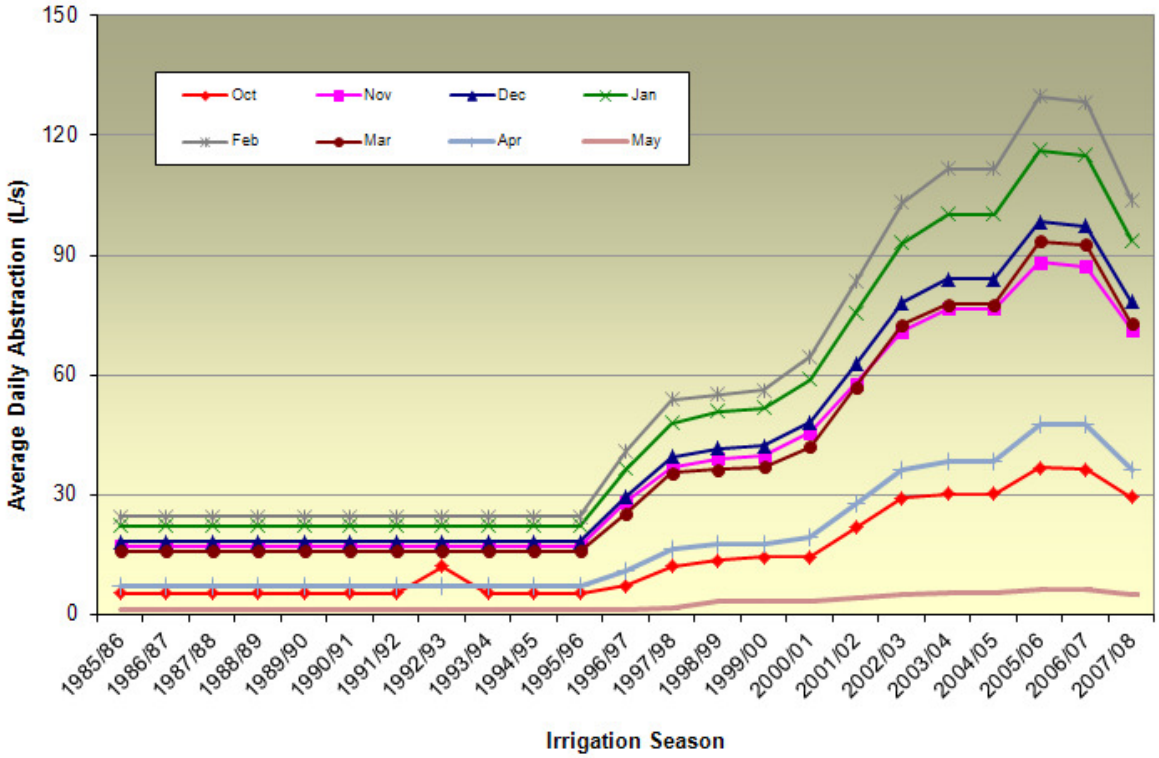

Figure 6-8: Tukituki River at Tapairu Rd. Trend of Average Daily Abstraction (L/s)

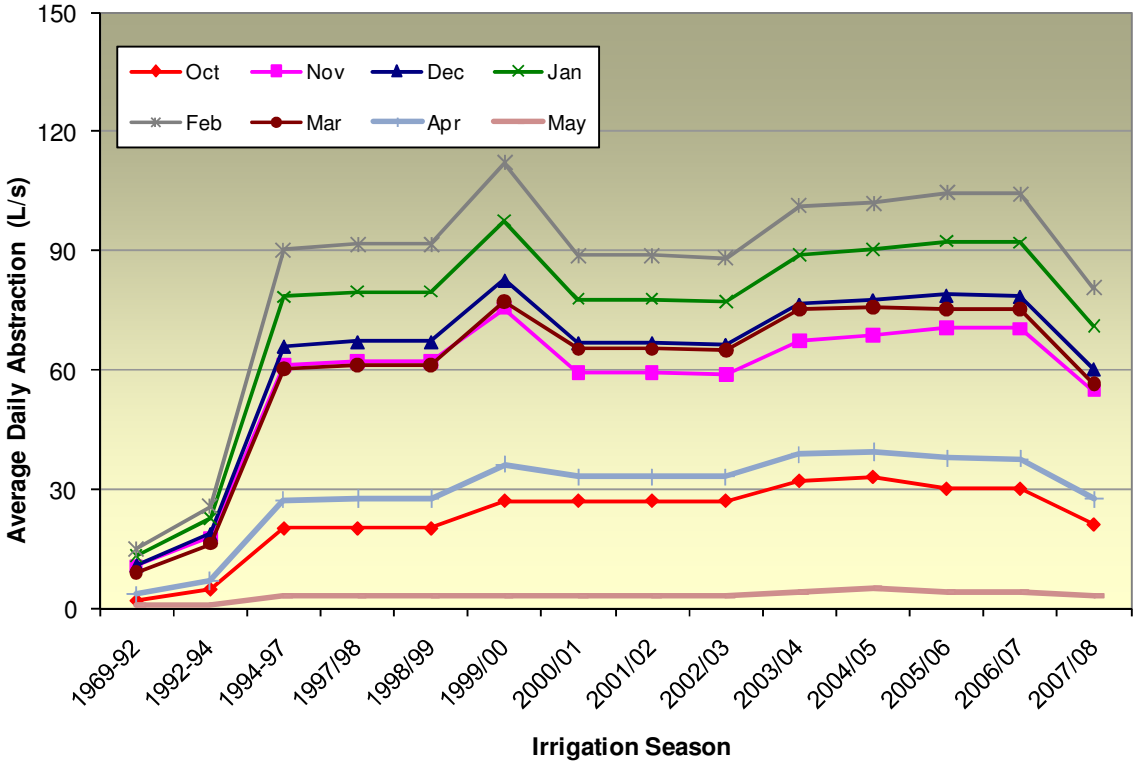

Figure 6-9: Waipawa River at RDS. Trend of Average Daily Abstraction (L/s)

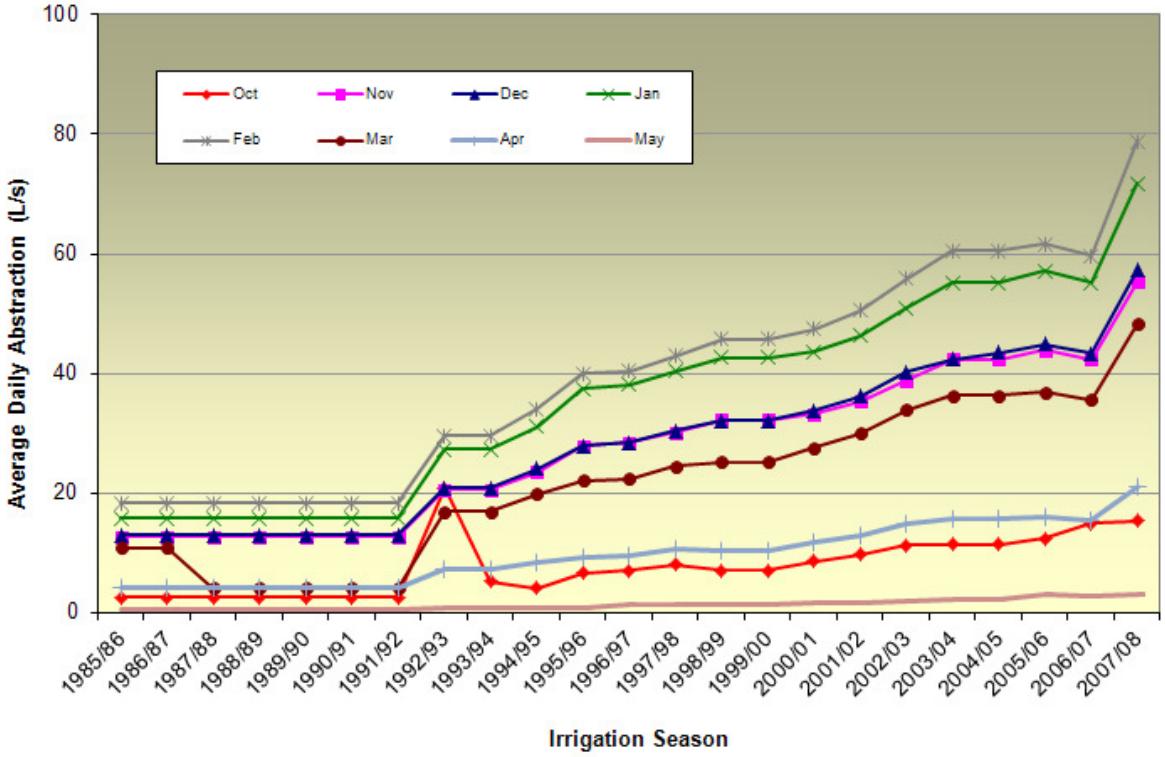

Figure 6-10: Tukituki River at Red Bridge. Trend of Average Daily Abstraction (L/s)

6.4 Tukituki Catchment Naturalised River Flow

The average daily abstraction dataset for each of the flow recorder sites has been added to the dataset of daily average flow recorded at each site. The process is cumulative whereby all abstractions above a recorder site are summed, including abstractions above an additional recorder site upstream. For example, Tukipo at SH58 is upstream of Tukituki at Tapairu Rd and all abstractions above SH50 are included in the Tapairu Rd assessment.

The resulting flow datasets represent the naturalised flow records for the Tukipo at SH50, Tukituki at Tapairu Rd, Waipawa at RDS and Tukituki at Red Bridge sites for the period 1 July 1969 to 30 June 2008. Sections 6.4.1 to 6.4.4 detail the naturalised flow data for each site in the Tukituki catchment.

6.4.1 Tukipo at SH50 Naturalised Flow

Actual recorded flow data for the Tukipo at SH50 begins in 1976. To create a naturalised flow dataset beginning in 1969 it was necessary to derive a synthetic actual flow record for the site between 1969 and 1976.

A water balance hydrological model (AWBM) was developed for the catchment. Three raingauges within the catchment have daily rainfall data available prior to 1969 and were still operating in conjunction with the Tukipo at SH50 flow recorder (from 1976) so that calibration of the water balance model was able to be carried out.

Measured evaporation data is also available within the catchment.

The AWBM model produced variable results. Calibration was primarily aimed at matching periods of low flow and long recessions, with the results giving a good match at certain times and a less desirable match at other times. This is perhaps a reflection of the quality of the rainfall data or an inadequate spatial representation.

The AWBM was not considered to provide accurate enough results to create a synthetic flow record for the Tukipo at SH50 between 1969 and 1976. Opus (1997) also conducted a water balance modelling process and reached a similar conclusion.

Therefore, the method adopted by Opus (1997) of using a flow to flow rating between the Tukipo at SH50 and Tukituki at Tapairu Rd sites was used here to see if a better result could be obtained. As flow records at Tukituki at Tapairu Rd do not begin until 1987 this method requires the development of a synthetic flow record at Tapairu Rd (Section 6.4.2) prior to this date so that it can be rated to represent Tukipo at SH50.

The period of concurrent actual flow data at the two sites between 1987 and 2008 is used to create a rating relationship. Flow duration percentile values (1% to 100%) have been calculated for each site over this period and paired together to create a rating relationship to convert Tapairu Rd flow to SH50 flow. The paired values are presented in Table 6-4 and the resulting plot is contained in Appendix A.

The Tukituki at Tapairu Rd synthetic flow data between 1969 and 1976 (Section 6.4.2) is applied to the rating relationship to derive a synthetic flow record for the Tukipo at SH50 site.

The derived daily abstraction dataset for the Tukipo at SH50 (Section 6.3.4) is added to the daily average recorded flow data to create a naturalised flow record.

Table 6-5 details flow statistics for the actual recorded flow and the naturalised flow data for the Tukipo River at SH50. All the tabled statistics are for daily flow.

Table 6-4: Tukituki at Tapairu Rd and Tukipo at SH50 Rating Relationship Pairs (L/s)

Tukituki at Tapairu Rd	Tukipo at SH50		Tukituki at Tapairu Rd	Tukipo at SH50		Tukituki at Tapairu Rd	Tukipo at SH50
1574	79		6608	524		13253	1228
1817	106		6761	540		13645	1260
1968	126		6909	556		14009	1306
2110	140		7043	571		14421	1345
2238	154		7174	584		14813	1390
2375	166		7335	599		15292	1430
2495	177		7463	610		15680	1480
2663	191		7600	625		16027	1523
2847	202		7722	643		16667	1567
2988	214		7887	655		17195	1625
3183	225		8074	668		17737	1689
3350	236		8229	688		18221	1769
3501	249		8450	709		19088	1829
3668	259		8632	726		19814	1914
3849	270		8791	746		20492	1981
3987	280		8935	768		21255	2089
4138	289		9087	782		21979	2187
4317	299		9264	805		23090	2311
4521	312		9477	823		24255	2413
4681	321		9643	841		25300	2533
4826	333		9831	861		26462	2689
4954	346		10058	884		27564	2827
5110	356		10280	902		29535	3006
5238	368		10489	927		31707	3227
5388	381		10720	947		33461	3471
5509	393		10904	967		36375	3717
5621	405		11090	992		40473	4160
5758	417		11281	1021		45150	4684
5870	432		11519	1046		52349	5619
5992	448		11742	1077		60934	6714
6105	460		12005	1104		78059	8499
6239	476		12280	1132		109055	12221
6368	494		12580	1162		525960	60421
6493	511		12902	1196			

Table 6-5: Flow Statistics (L/s) for Actual and Naturalised Tukipo at SH50 (1969-2008)

	Mean	Median	Min	MALF	Q_{95}	Q_{90}	Q_{80}	Max
Naturalised Flow	1552	847	54	165	159	222	349	94659
Actual Flow *+synthetic 1969-76*	1549	846	54	161	153	216	344	94659

It is evident that the current volume of consented abstraction from the Tukipo River has very minimal effect on the low to median flow range. The naturalised daily median flow is 847 L/s compared to the actual recorded daily median flow of 853 L/s. The actual and naturalised daily minimum flow is the same at 54 L/s

The naturalised Q_{95} flow (159 L/s) is 5 L/s greater than the actual Q_{95} (154 L/s).

6.4.2 Tukituki at Tapairu Rd Naturalised Flow

Actual recorded flow data for the Tukituki at Tapairu Rd begins in 1987. Synthetic flow data between 1969 and 1987 has been created to extend the flow record back in time.

The same methodology as adopted by Opus (1997) is used:

1. A rating relationship with the Tukipo at SH50 site is developed to create flow at Tapairu Rd between 1976 and 1987
2. Results of an AWBM water balance model, based on catchment rainfall and evaporation and calibrated to actual flow data, are used to create flow at Tapairu Rd between 1969 and 1976.

An AWBM approach could have been used to develop flow data for the entire 1969 to 1987 period, but deriving flow from the upstream Tukipo at SH50 site was considered more accurate so this has been used from the start of the Tukipo at SH50 record in 1976.

Flow exceedence percentile values are derived for both the Tukituki at Tapairu Rd and Tukipo at SH50 sites for the period of concurrent recorded flow data (1987 onwards).

The exceedence values are paired to create a rating relationship that can be applied to the Tukipo at SH50 flow record to create a synthetic Tukituki at Tapairu Rd flow record. The paired values are detailed in Table 6-4 and the resulting plot is contained in Appendix A.

Opus (1997) developed an AWBM water balance model for the Tukituki at Tapairu Rd site. The model used catchment rainfall and evaporation data and was calibrated against the flow recorded at the Tapairu Rd site. The flow created by the model produced more accurate results than the AWBM model developed (Section 6.4.1) for the Tukipo at SH50 catchment (Opus 1997).

The synthetic flow data created by the AWBM between 1969 and 1976 is adopted here and in conjunction with the flow data derived between 1976 and 1987 (by rating correlation with the Tukipo at SH50 site) creates a period of synthetic daily flow record for the Tukituki at Tapairu Rd between 1969 and 1987.

The synthetic daily flow data is combined with the actual daily flow data to create an entire flow dataset between 1969 and 2008.

The derived daily abstraction dataset for the Tukituki at Tapairu Rd and Tukipo at SH50 are combined to create a record of all abstractions above the Tukituki at Tapairu Rd site. This is added to the daily average recorded flow data to create a naturalised flow record.

Table 6-6 details flow statistics for the naturalised and actual flow data for the Tukituki River at Tapairu Rd. All the tabled statistics are for daily flow.

Table 6-6: Flow Statistics (L/s) for Actual and Naturalised Tukituki at Tapairu Rd (1969-2008)

	Mean	Median	Min	MALF	Q_{95}	Q_{90}	Q_{80}	Max
Naturalised Flow	15779	9727	1309	2591	2416	3258	4982	582128
Actual Flow *+synthetic 1969-87*	15763	9708	1309	2555	2375	3219	4942	582128

The current volume and rate of consented abstraction from the Tukituki River catchments above the Tapairu Rd site has only a minor effect on the flow statistics.

The naturalised minimum flow is the same as the actual minimum flow at 1309 L/s. This is below the minimum flow for the site so no water abstraction would have been required to cease during low flow events.

The naturalised Q_{95} flow (2416 L/s) is 47 L/s greater than the actual Q_{95} (2369 L/s).

Mean annual low flow between the two datasets varies by 32 L/s.

6.4.3 Waipawa at RDS Naturalised Flow

Actual recorded flow data exists for the Waipawa at RDS site from 1988 onwards. Synthetic flow data between 1969 and 1988 is created to develop a complete flow dataset from 1969 onwards.

The Opus (1997) methodology of using a rating relationship of flow duration percentile values (1% to 100%) between Waipawa at RDS and Tukipo at SH50 is adopted here. The Waipawa River is influenced by groundwater interaction with areas of gains and losses of flow and is therefore problematic to model using the AWBM approach.

The paired values used in the rating relationship are presented in Table 6-7 and the resulting plot is contained in Appendix A.

Table 6-7: Tukipo at SH50 and Waipawa at RDS Rating Relationship Pairs (L/s)

Tukipo at SH50	Waipawa at RDS		Tukipo at SH50	Waipawa at RDS		Tukipo at SH50	Waipawa at RDS
1574	79		6608	524		13253	1228
1817	106		6761	540		13645	1260
1968	126		6909	556		14009	1306
2110	140		7043	571		14421	1345
2238	154		7174	584		14813	1390
2375	166		7335	599		15292	1430
2495	177		7463	610		15680	1480
2663	191		7600	625		16027	1523
2847	202		7722	643		16667	1567
2988	214		7887	655		17195	1625
3183	225		8074	668		17737	1689
3350	236		8229	688		18221	1769
3501	249		8450	709		19088	1829
3668	259		8632	726		19814	1914
3849	270		8791	746		20492	1981
3987	280		8935	768		21255	2089
4138	289		9087	782		21979	2187
4317	299		9264	805		23090	2311
4521	312		9477	823		24255	2413
4681	321		9643	841		25300	2533
4826	333		9831	861		26462	2689
4954	346		10058	884		27564	2827
5110	356		10280	902		29535	3006
5238	368		10489	927		31707	3227
5388	381		10720	947		33461	3471
5509	393		10904	967		36375	3717
5621	405		11090	992		40473	4160
5758	417		11281	1021		45150	4684
5870	432		11519	1046		52349	5619
5992	448		11742	1077		60934	6714
6105	460		12005	1104		78059	8499
6239	476		12280	1132		109055	12221
6368	494		12580	1162		525960	60421
6493	511		12902	1196			

The derived daily abstraction dataset for the Waipawa at RDS is added to the daily average recorded flow data to create a naturalised flow record.

Table 6-8 details flow statistics for the actual recorded flow and the naturalised flow data for the Waipawa at RDS. All the tabled statistics are for daily average flow.

Table 6-8: Flow Statistics (L/s) for Actual and Naturalised Waipawa at RDS (1969-2008)

	Mean	Median	Min	MALF	Q_{95}	Q_{90}	Q_{80}	Max
Naturalised Flow	14915	8921	1358	2843	2603	3372	4638	626690
Actual Flow *+synthetic 1969-88*	14900	8907	1358	2817	2584	3338	4620	626679

The current volume and rate of consented abstraction from the Waipawa catchment above the RDS site has a minor effect on the flow regime.

The naturalised and actual minimum flows are the same at 1358 L/s. This is below the minimum flow for the site so no water abstraction would have been required to cease during low flow events.

The naturalised Q_{95} flow (2603 L/s) is 19 L/s greater than the actual Q_{95} (2584 L/s).

Mean annual low flow between the two datasets varies by 26 L/s.

6.4.4 Tukituki at Red Bridge Naturalised Flow

The Tukituki at Red Bridge site has been in operation since 1968 and therefore requires no record extension for the purposes of this investigation.

Gaps in the record have been filled using a correlation with the upstream site, Tukituki at Shag Rock (MWH 2009).

The derived daily abstraction datasets for the Tukipo at SH50, Tukituki at Tapairu Rd, Waipawa at RDS and Tukituki at Red Bridge are combined to create a record of all abstractions above the Tukituki at Red Bridge site. This is added to the daily average recorded flow data to create a naturalised flow record.

Table 6-9 details flow statistics for the actual recorded flow and the naturalised flow data for the Tukituki River at Red Bridge.

All the tabled statistics are for daily flow with the exception of the 7-day Q_{95} ($Q_{95,7}$) which is averaged over 7 days.

Table 6-9: Flow Statistics (L/s) for Naturalised and Actual Tukituki at Red Bridge (1969-2008)

	Mean	Median	Min	MALF	Q_{95}	Q_{90}	Q_{80}	Max
Naturalised Flow	434007	21700	1396	5913	5913	7470	10452	2028495
Actual Flow	43950	21656	1343	5884	5811	7367	10367	2028495

The current volume and rate of consented abstraction from the Tukituki River catchments above the Red Bridge site has a small effect on the flow statistics.

The naturalised minimum flow is 1396 L/s compared to a flow of 1343 L/s after abstractions have occurred.

The naturalised Q_{95} flow (5913 L/s) is 101 L/s greater than the actual Q_{95} (5812 L/s).

Mean annual low flow between the two datasets varies by 29 L/s.

7 Maraetotara at Te Awanga

A naturalised flow dataset has been derived for the Maraetotara River at Te Awanga. This site is a low flow monitoring site for the minimum flow levels as defined in the RRMP (HBRC, 2006).

To derive a naturalised flow dataset for the Maraetotara at Te Awanga site the methodology detailed in Table 4-1 was followed.

A synthetic actual flow record for the Te Awanga site has been derived from the Maraetotara at Waimarama Rd recorder site before this was naturalised by adding on surface water abstractions.

7.1 Recorded Flow Data

Table 7-1 details the main flow recording sites in and around the Maraetotara catchment.

There is currently no continuous flow record for the Maraetotara at Te Awanga monitoring site, although numerous flow gaugings have been completed there between 1983 and 2008.

A continuous flow recorder operates further up the catchment. The Maraetotara at Waimarama Rd site has been recording flow data from 1991 to 2008. A naturalised flow dataset was previously created for the Waimarama Rd between 1969 and 1996 site by Opus (1997).

MWH (2009) created a naturalised flow record for the Maraetotara at Te Awanga site covering the period 1997 to 2008. The methodology involved correlating the recorded flow data at Waimarama Rd with the Te Awanga site and creating a synthetic flow record. The synthetic flow record was then naturalised by adding back in the daily surface water abstraction from the catchment.

Numerous concurrent flow gaugings exist between the Waimarama Rd and Te Awanga sites.

Table 7-1: Maraetotara River and Nearby Catchment Recorder Sites

Site No.	River	Site Name	Period	Easting	Northing	Recording Authority
23302	Maraetotara	Waimarama Rd Waimarama Rd (Naturalised)	1991-2008 1969-1996	2848700	6156100	HBRC
23304	Maraetotara	Te Awanga (flow gaugings only)	1983-2008	2852120	6166280	HBRC
23209	Otane	Glendon	1964-2008	2816652	6140596	NIWA

This investigation seeks to extend the current naturalised flow dataset for the Maraetotara at Te Awanga (MWH 2009) to cover the period from 1969 onwards.

7.2 Consented Abstractions

Consent records of surface water abstractions have been supplied by HBRC. MWH (2009) provides a detailed summary of the consent information.

Detailed summaries of the consent information are provided by MWH (2009).

7.3 Metered Actual Water Use

MWH (2009) presented analyses of metered surface water abstraction in the Maraetotara catchment.

There is insufficient data available to derive catchment specific conclusions on water abstraction usage and rates within the Maraetotara catchments, therefore the Maraetotara meter dataset is combined with the neighbouring Tukituki metered abstraction dataset (Section 6.3).

7.3.1 Actual Use by Individual Meter

Figure 7-1 shows the actual water use as a percentage of allocation for the 18 Maraetotara and Tukituki meter sites.

The January and February months commonly show the highest percentage of water use, although there is variation between users. Only seven of the users achieve more than 50% of their allocation in any month. The maximum monthly usage for each site ranges from 0% to 97%.

Three abstractors achieve greater than 75% use of their allocation for at least one month. The landuse types stated for these consented abstractions are one of each of pastoral farming, stockyard and cropping.

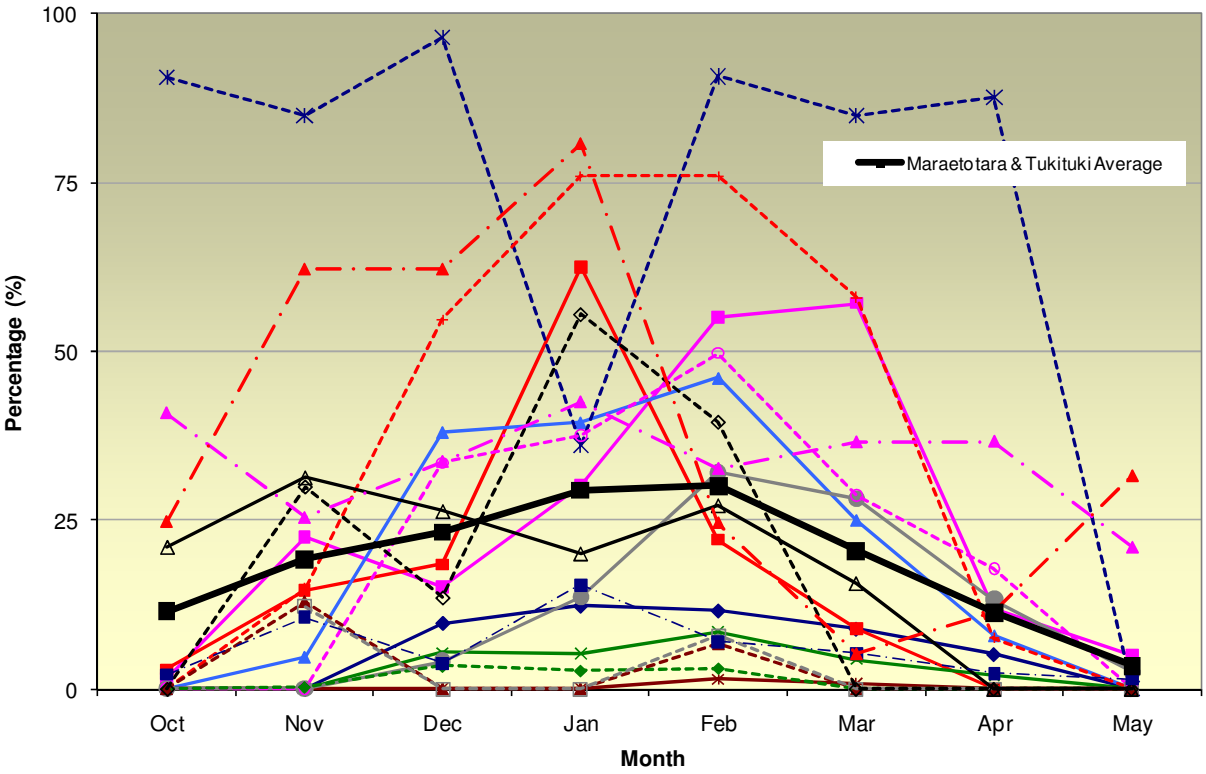

Figure 7-1: Maraetotara and Tukituki Catchment Metered Actual Surface Water Abstraction

7.3.2 Actual Use by Landuse Type

The metered abstraction data has been divided up into the landuse category at each metered location. Figure 7-2 shows the variation of the percentage actual water use for the Maraetotara and Tukituki catchments for five landuse types of pastoral farming, cropping, vineyard, orchard and other miscellaneous.

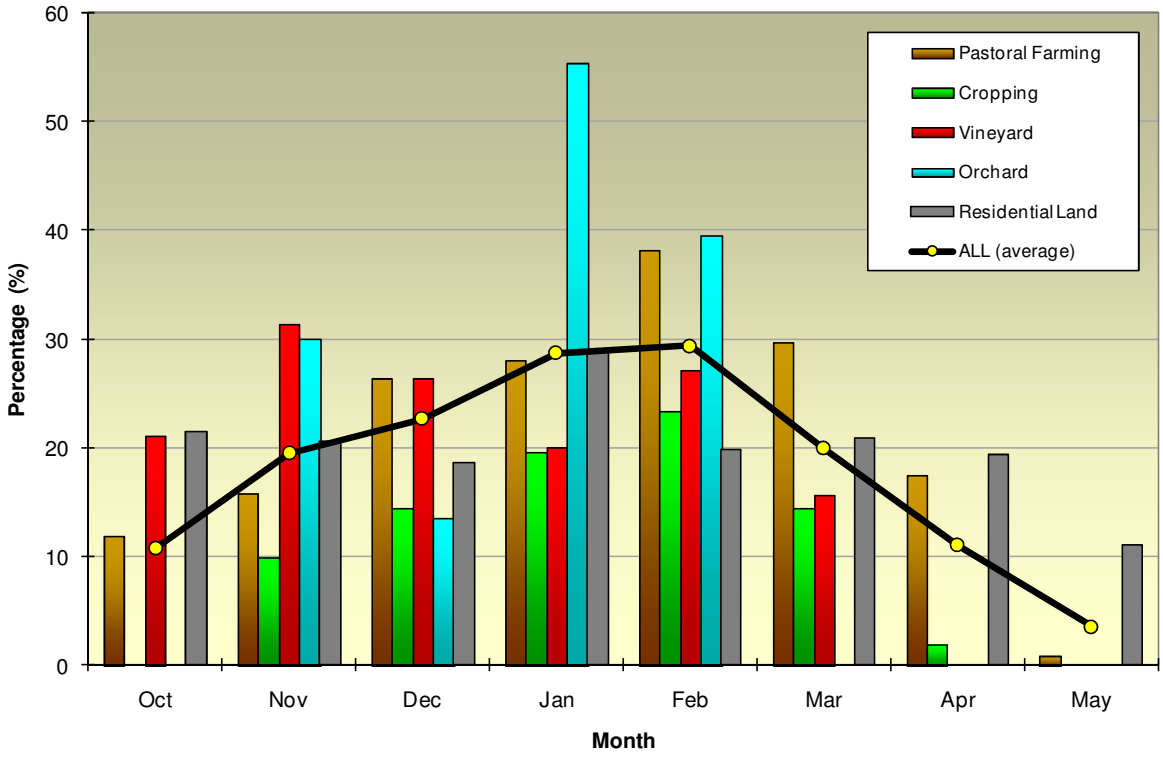

Figure 7-2: Maraetotara & Tukituki Metered Data. Percentage Actual Water Use by Landuse

7.3.3 Estimated Total Actual Daily Abstraction

The metered abstraction data has used to derive the total abstraction from the Maraetotara River. This was then applied to the river flow data to produce a naturalised flow record.

All the consents that have been issued for surface water abstraction in the Maraetotara catchment have been for three types of landuse; pastoral farming, cropping and residential. The average percentage of metered actual use for each landuse is calculated and presented in Table 7-2.

Table 7-2: Average Monthly Percentage of Actual Water Use by Landuse Type

	Pastoral Farming	Cropping	Residential		Average
October	12	0	23		12
November	18	10	21		16
December	26	15	16		19
January	28	20	23		24
February	38	23	17		26
March	30	14	17		20
April	18	2	15		11
May	1	0	18		6

All the surface water abstraction consents for the Maraetotara catchment have been grouped on an irrigation season basis from 1969/97 to 2007/08. For each irrigation season the total allocated volume (m^3/week) is derived for three landuse categories:

- Pastoral farming
- Cropping
- Residential

The total allocation volumes are divided further into total daily allocated volumes (m^3/day) per landuse, and then into an average daily abstraction rate.

The percentages of actual water use (Table 7-2) for each landuse and month are applied to the average daily allocation to derive the **actual** daily average abstraction rate of water from the Maraetotara River.

Figure 7-3 details the actual average daily abstraction (L/s) for each month of each irrigation season. The highest water use rates occur in February.

A dataset of average daily abstraction is compiled from 1969-2008 with adjustments made where necessary to account for periods of irrigation bans. This dataset is used to naturalise the Maraetotara River flow (Section 7.4).

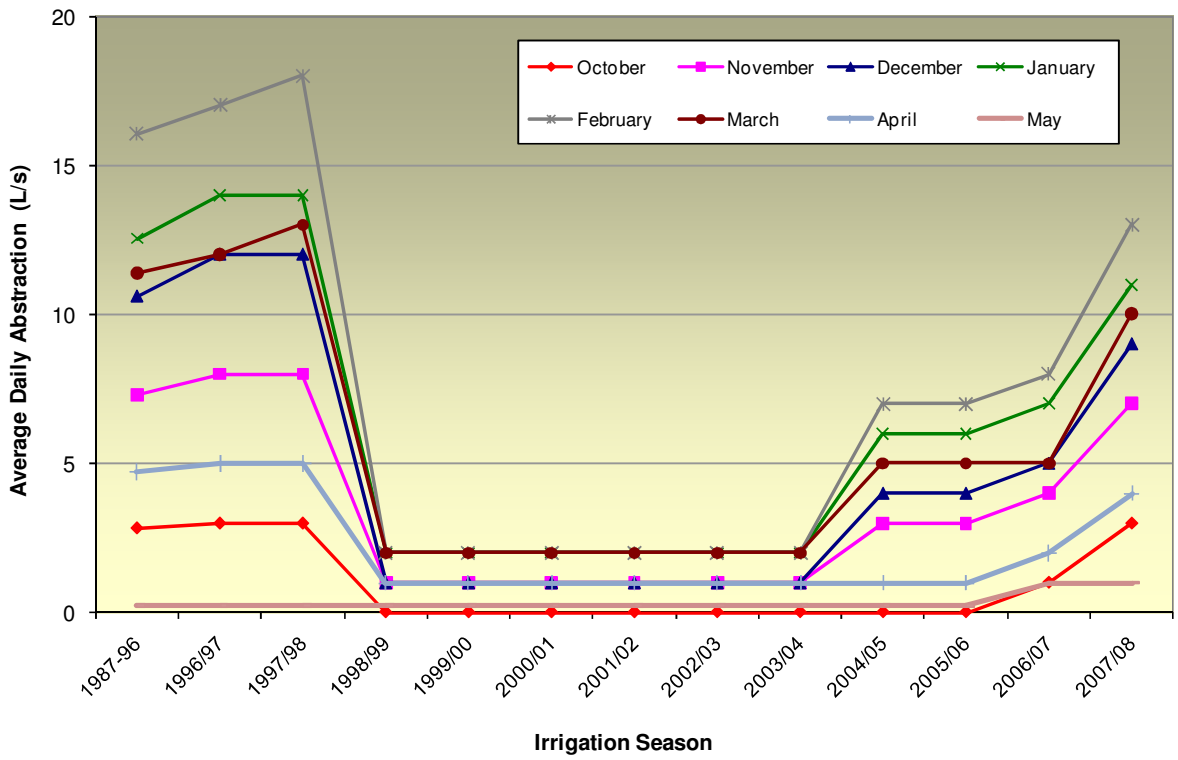

Figure 7-3: Maraetotara River Trend of Average Daily Abstraction (L/s)

The amount of allocation and abstraction between 1969 and 1986 is assumed as zero.

7.4 Naturalising Maraetotara River Flow

The derived daily abstraction data is added to the Maraetotara at Te Awanga flow record to create a naturalised flow record for the site.

As no recorded flow data exists for the Te Awanga site a synthetic record is derived from the Maraetotara at Waimarama Rd recorder as detailed by MWH (2009).

7.4.1 Synthetic Maraetotara at Te Awanga Flow Record

Continuously recorded flow data does not exist for the Maraetotara at Te Awanga site. A flow record for the site can be derived using the upstream flow recorder Maraetotara at Waimarama Rd, for which data is available from 1991 to 2008.

Opus (1997) previously created a naturalised Maraetotara at Waimarama Rd flow record for the period 1969 to 1996.

The Maraetotara at Waimarama Rd flow recorder is sited approximately 17 km upstream of the Maraetotara at Te Awanga site draining an area of 63 km^2, compared to 113 km^2 for Te Awanga.

The method used to create a flow record for Te Awanga was to base it on the Waimarama Rd record by using a correlation between the two sites.

A total of 31 concurrent flow gaugings exist between the two sites. This provides a dataset upon which to derive a correlation so that Waimarama Rd flow can be converted to Te Awanga flow.

The flow gaugings for both sites can be considered 'modified' (i.e. affected by abstractions). Over the period of record of the concurrent gaugings the number of consented abstractions operating between the two sites ranges between one (1998-2004) and four (1996-98). If all four had been operating to their maximum allocation at once a total of 54 L/s would be abstracted. This value is very conservative and also falls within the accepted margin of error for flow measurement (±8%) for many of the concurrent gauging pairs so is ignored and no adjustments are required.

As detailed in MWH (2009) a combination of a linear regression and a power regression have been used to convert flow at Waimarama Rd to flow at Te Awanga. The linear equation applies to Waimarama Rd flows greater than 2,500 L/s (four times the median flow), and the power regression applies to flows less than this. The equations are (MWH 2009):

If Waimarama Rd flow ≤2,500 L/s then;

$$\textit{Te Awanga} = 0.1515 \times \textit{Waimarama Rd}^{1.2801}$$

Or else if Waimarama Rd > 2,500 L/s then;

$$\textit{Te Awanga} = (1.4796 \times \textit{Waimarama Rd}) - 328.71$$

The correlation plots and the two regression lines are contained in Appendix A.

As detailed above, the Maraetotara at Waimarama Rd flow record commences in 1991 so a period of synthetic flow data needs to be derived to extend the flow record at the site, and therefore also at Te Awanga, back to 1969.

Two methods have been trialled to derive a synthetic flow record at Waimarama Rd:

1. A water balance model using AWBM
2. Correlation with the nearby Otane at Glendon flow recorder

An AWBM model was built for the Maraetotara catchment to the Waimarama Rd recorder. There were sufficient rainfall records within the catchment that began in the 1960's or earlier and continue to the present. Flow data at the Waimarama Rd recorder is available to use as calibration since 1991.

The output of flow data at Waimarama Rd from the calibrated AWBM model was considered satisfactory overall. However, it under/over-estimated a number of recessions and low flow extremes.

The second method created a synthetic flow record at Waimarama Rd based on a flow exceedence rating correlation between the Waimarama Rd and Otane at Glendon flow data. The Otane catchment is the representative basin for the area and has similar limestone geology to the Maraetotara catchment. The resulting relationship plot is contained in Appendix A.

Comparison of the synthetic flow record created by this method to the actual recorded data from 1991 showed this method to produce a more accurate representation of flows, particularly at time low flows and during recessions. A problem arose at several times of extreme low flows when zero flows were recorded in the Otane. Using the rating correlation this results in a period of "flat line" flow record in the data created for Waimarama Rd.

It was concluded to create the synthetic flow record for the Maraetotara at Waimarama Rd site based on the flow rating relationship with the Otane at Glendon site. At the times when flow at Otane dropped to zero and flat lining occurred in the synthetic Waimarama Rd data, the results from the AWBM were used replace this data. The AWBM data used for each period were adjusted/ramped to match the synthetic data. This provides a natural recession and subsequent increase in flow rather than a period of flat lining flow.

The flow rating relationship was also used to fill a number of gaps that exist in the Waimarama Rd data record from 1991 onwards.

A number of gaps exist in the Otane at Glendon data record, and in these instances the output from the AWBM model was used to fill the corresponding gaps in the synthetic data record.

All gaps were able to be filled except for one large gap of 235 days (11/3/1980 to 1/11/1980) caused by a gap in the Otane at Glendon record. It was decided to leave this gap in the synthetic data as it was too long to confidently fill with the AWBM output.

The total daily flow dataset now available for Maraetotara at Waimarama Rd was applied to the regression equations detailed above to create the Maraetotara at Te Awanga daily average flow data series.

7.5 Maraetotara at Te Awanga Naturalised River Flow

Two datasets have been created from which the naturalised flow for the Maraetotara River at Te Awanga can be derived:

- Daily average flow – Maraetotara at Te Awanga (Section 7.4.1)
- Daily average consented abstraction (Section 7.3.3)

A spreadsheet was used to add all the abstraction data to the derived Maraetotara at Te Awanga flow and the resulting dataset represents the naturalised Maraetotara at Te Awanga flow record for the period 1 July 1969 to 30 June 2008.

The rate of abstraction from the Maraetotara River is small and within the accepted margin of error for flow measurement (±8%) but it was considered worthwhile to carry through with the naturalisation process rather than ignore it.

Table 7-3 details flow statistics for the naturalised flow data and the synthetic 'actual' flow data at Te Awanga as well as statistics for the actual and synthetic data record at Waimarama Rd.

All the tabled statistics are for daily flow.

Table 7-3: Flow Statistics (L/s) for Actual and Naturalised Maraetotara Sites

	Mean	Median	Min	MALF	Q_{95}	Q_{90}	Q_{80}	Max
Waimarama Rd *Actual 1991-08*	1101	642	257	395	362	409	462	49587
Waimarama Rd *Actual+Synthetic 1969-08*	1174	663	249	363	352	401	455	67371
Te Awanga *Actual (Synthetic) 1969-08*	1384	620	177	290	277	325	383	99353
Te Awanga *Naturalised 1969-08*	1386	621	180	293	280	328	386	99353

Due to the relatively small amount of abstraction from the Maraetotara River the figures for the Te Awanga actual (synthetic) and naturalised are very similar.

The naturalised Q_{95} flow (280 L/s) is 3 L/s greater than the actual Q_{95} (277 L/s).

8 Porangahau River below Mangaorapa

The Porangahau catchment contains two continuous flow recorders (Taurekaitai Stream at Wallingford and Mangaorapa at Mangaorapa Rd) as detailed in Table 8-1. The nearby Akitio at Weber site (operated by Horizons Regional Council) is also detailed.

The Porangahau at Wallingford site monitors flow from the north of the Porangahau catchment from an area of 286.5 km^2. The Mangaorapa at Mangaorapa Rd sites measures flow from the south-west portion of the Porangahau catchment from an area of 208 km^2.

The catchment area of the Porangahau River above the Porangahau township is approximately 700 km^2. The entire catchment area to the coast is approximately 845 km^2.

Table 8-1: Flow Monitoring Recorders in and around the Porangahau Catchment

River	Site Name	Site No.	Period	Easting	Northing	Catchment Area (km^2)
Porangahau	Wallingford	24325	Apr 1980- present	2815600	6104800	286.5
Mangaorapa	Mangaorapa Rd	24304	Jun 2000- present	2812300	6095300	208
Akitio	Weber	25003	Nov 1979 – Apr 2001	2791889	6083211	123

8.1 Deriving Flow Data

The purpose of this investigation was to create a flow data record for the lower reaches of the Porangahau catchment and to naturalise this flow data.

The methodology to create a synthetic flow record for the lower Porangahau catchment was:

- Use Porangahau at Wallingford data record as the base period (1980 onwards)
- Extend the Mangaorapa at Mangaorapa Rd flow record back to 1980
- Use the Mangaorapa at Mangaorapa Rd to develop a flow record for the entire Mangaorapa catchment at the confluence with the Porangahau River
- Use the Porangahau at Wallingford data and concurrent flow gaugings to create a flow record for the Porangahau catchment at the confluence with the Mangaorapa River
- Combine the two generated flow records to create a flow data series for the Porangahau River above the Porangahau township or near SH52

Two methods have been used to extend the flow record for the Mangaorapa at Mangaorapa Rd using the Porangahau at Wallingford flow record:

1. A flow exceedence rating relationship
2. Concurrent gaugings relationship

Flow exceedence percentile values for the period July 2000 to January 2010 were used to create a rating relationship between the Porangahau at Wallingford and Mangaorapa at Mangaorapa Rd sites. The relationship can be used to convert recorded flow at Wallingford to represent flow at Mangaorapa Rd.

The rating relationship was derived and the Porangahau at Wallingford flow record applied to it. The synthetic Mangaorapa flow output was compared to the actual recorded Mangaorapa flow for the period

that the recorder has been operating at the site (2000 to 2010). The results were less than encouraging; generally the synthetic data matched the timing of the actual data but there were differences at times of low flow and during recessions with the synthetic data underestimating the actual flow and on a number of occasions exhibiting a flat lining pattern.

The flat lining is due to the fact that zero flows are often recorded at the Porangahau at Wallingford site while there is still a varying amount of flow occurring in the Mangaorapa at Mangaorapa Rd.

The second method, using concurrent gaugings at the two sites, provides the relationship as shown in Figure 8-1.

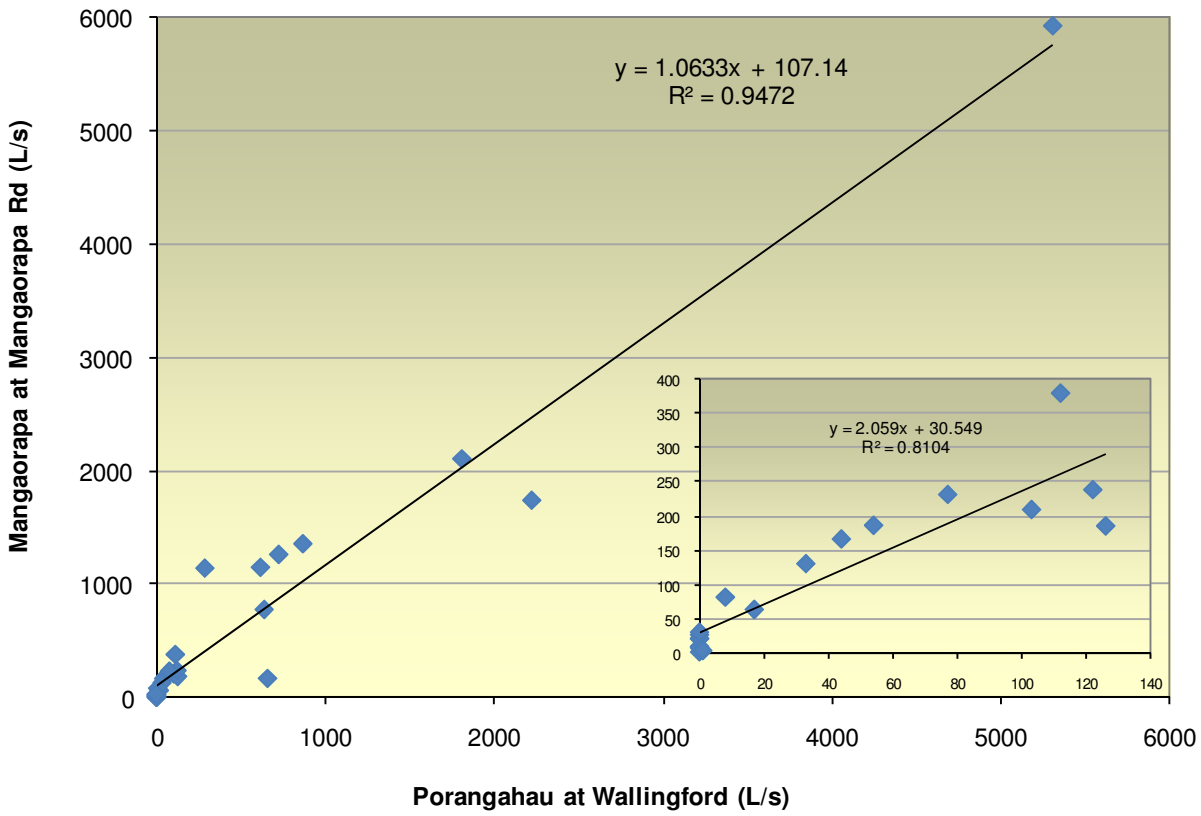

Figure 8-1: Porangahau Concurrent Flow Gaugings

The linear relationship shows a good fit with an R^2 value of 0.95, however the insert plot focuses on the smaller concurrent gaugings and illustrates the number of zero, or near zero, flows measured at Wallingford with a corresponding range (1 to 30 L/s) of flows concurrently measured at Mangaorapa.

As with the first method, applying this regression relationship to the Porangahau at Wallingford flow data to create a dataset for Mangaorapa at Mangaorapa Rd created less than satisfactory results – particularly at times of low flow.

The differing flow characteristics of the two sites mean the usefulness of this method of record extension is limited.

Flow data from a recorder site to the south in the Akitio catchment has been used to see if it would be more appropriate than the Porangahau catchment for extending the Mangaorapa at Mangaorapa Rd data record. The Mangaorapa catchment shares its southwest boundary with the Akitio catchment.

There are no concurrent flow gaugings between the two sites.

A flow exceedence rating relationship was developed between the Akitio at Weber and Mangaorapa at Mangaorapa Rd sites. The resulting plot is contained in Appendix A. The Akitio flow record, supplied by Horizons Regional Council, begins in 1979 and ends in 2001. This means there was only a relatively short period of concurrent flow record between the two sites – July 2000 to April 2001.

The synthetic Mangaorapa at Mangaorapa Rd flow derived from the rating relationship provided a very good match to the actual data for the July 2000 to April 2001 period. The synthetic data prior to this period was able to be compared to flow gaugings completed at Mangaorapa Rd between 1982 and 2000 but it proved not to be representative of the actual measured flow. The Akitio at Weber flow record was not used any further in developing synthetic flow data in the Mangaorapa catchment.

None of the above methods can accurately extend the Mangaorapa at Mangaorapa Rd flow record back. In terms of creating a flow record for the Porangahau River above the township, it was decided to focus on the period from July 2000 when there is continuous flow data at both the Porangahau and Mangaorapa sites.

The Mangaorapa at Mangaorapa Rd flow recorder site is 12 km^2 smaller than the entire Mangaorapa catchment at its confluence with the Porangahau River. It is therefore assumed that the recorded flow data at the site can be confidently used to create a synthetic flow record at the confluence by transferring the specific yield from the recorder site to the downstream location at the confluence.

The specific yield of the daily mean flow at Mangaorapa at Mangaorapa Rd (i.e. flow divided by catchment area – $l/s/km^2$) is derived for the catchment area of 208 km^2 and then multiplied by the catchment area of the Mangaorapa at Porangahau confluence (220 km^2) thereby creating a synthetic flow dataset at this location from 2000 onwards.

In the Porangahau catchment, concurrent gaugings are available between the Porangahau at Wallingford and a gauging site (Porangahau at Wilder Rd) which is close to the confluence with the Mangaorapa River.

The catchment area of the Porangahau at Mangaorapa Confluence is 470 km^2. Initially the specific yield method (as with the Mangaorapa catchment) was preferred to apply to the Porangahau at Wallingford daily flow record to create a flow dataset for the Porangahau at Mangaorapa Confluence.

A check on the specific yield for the Porangahau sites is detailed in Table 8-2. Concurrent gauging pairs between the sites were used as a check on the results. The specific yield approach produces comparable results to the concurrent gauging values between the two sites.

Table 8-2: Porangahau Specific Yield Check – Wallingford and Wilder Rd

Wallingford Gauged/Rated Flow		Convert Wallingford to Wilder Rd Flow (by specific yield)		Actual Wilder Rd Gauged Flow
L/s	***L/s/km²***	**L/s**		**L/s**
3	*0.011*	4.9		5
0	*0*	0		1
2	*0.007*	3.2		0
0	*0*	0		0
0	*0*	0		1
0	*0*	0		15
112	*0.397*	181		218
54	*0.191*	87		113
0	*0*	0		0
0	*0*	0		3
1	*0.004*	1.6		4
103	*0.365*	167		171

Therefore, the specific yield method was used to create a flow data record for the Porangahau at Mangaorapa Confluence based on the upstream Porangahau at Wallingford recorded flow data.

The daily mean flows from Wallingford were divided by the catchment area (282.3 km^2) to obtain the specific yield and were then multiplied by the catchment area to the Mangaorapa confluence (470 km^2).

The resulting flow datasets for the Porangahau at Mangaorapa Confluence and the Mangaorapa at Mangaorapa Rd are combined to create a daily mean flow dataset for the Porangahau River below the Mangaorapa Confluence starting in July 2000.

Table 8-3 details flow statistics for the recorded data and derived synthetic data in the Porangahau catchment.

Table 8-3: Flow Statistics (L/s) for Porangahau Catchment

Site	Mean	Median	Min	MALF	Q_{95}	Q_{90}	Q_{80}	Max
Porangahau at Wallingford (1980-2010)	2361	393	0	9	7	15	29	517246
Porangahau at Mangaorapa – Synthetic (1980-2010)	3930	659	0	15	12	24	48	861161
Mangaorapa at Mangaorapa Rd (2000-2010)	2865	1025	1	251	75	106	337	254359
Mangaorapa at Porangahau Conf – Synthetic (2000-2010)	3047	1108	1	294	80	119	365	269034
Porangahau at Mangaorapa Conf - Synthetic (2000-2010)	4132	787	0	16	11	21	43	247740
Porangahau below Mangaorapa – Synthetic (2000-2010)	**7434**	**1989**	**1**	**319**	**103**	**155**	**539**	**487874**

River flow in the Porangahau catchment can reach very low levels, and zero flows have been measured at the Wallingford site.

The synthetic flow record for the lower Porangahau catchment (Porangahau at below Mangaorapa confluence) has a minimum flow of 1 L/s and a mean annual low flow (MALF) of 319 L/s. The Mangaorapa River contributes relatively higher flows in low flow periods.

8.2 Consented Abstractions

Consent records of surface water abstractions from the Porangahau catchment have been supplied by HBRC.

Only four consents to take surface water have been granted in the catchment since 1969. One was for crop irrigation in the Mangaorapa catchment with a maximum weekly allocation of 52 m^3/s. This consent operated between 1969 and 1998. This is a small abstraction, with the daily averaging rate less than 1 L/s – although the maximum rate of take was set at 12.6 L/s.

The three other consented takes were for potable water supply for Porangahau and Porangahau Beach townships. The original consent was from 1987 to 1998 (5 L/s) and the other two were renewals of this (10 L/s).

8.3 Naturalising Porangahau River Flow

Comparing the four consented abstractions from the Porangahau catchment over time, only one was above the Porangahau at below Mangaorapa site for which a flow record has been derived here. The water supply consents for the township were located below this site.

The daily average rate of abstraction for the one consent is less than 1 L/s. This is inconsequential when considering the margin of error associated with measurement of river flow (±8%). In addition, the creation of the Porangahau at below Mangaorapa dataset includes uncertainties associated with extrapolating flow data from one recorder site to another location.

Adjustments for abstraction were not carried out in this instance and the flow dataset as derived (Section 8.1) was accepted as the naturalised flow dataset.

9 Discussion

This investigation has derived naturalised river flow records for seven key sites on six catchments in the Hawke's Bay region.

The methodology followed in the flow naturalisation process consists of five key steps (Section 4):

1. Derive a dataset of average daily flow at the flow monitoring site to be used
2. Analysis of resource consent records to derive an average daily allocation for all landuses for each irrigation season
3. Collate the available metered abstraction data, compare to consented allocation volume (for the metered abstraction) and derive the percentage actual water use for those metered abstractions
4. Apply the percentage actual water use (Step 3) to the average daily allocation of all consent records (Step 2) to produce estimated actual daily average abstraction for the catchment.
5. Add to the average daily river flow data to derive a Naturalised Flow Dataset.

Sections 5 to 8 detail the results for the Tutaekuri, Tukituki, Maraetotara and Porangahau catchments respectively and present the actual water used (as measured by meters) as a percentage of the allocated amount.

Figure 9-1 summarises the results for all the metered surface water abstractions in the study catchments. The results are also divided into the landuse category the abstracted water is used for.

The average percentage of metered actual water used for all landuses ranges between 7% and 22%. Orchard irrigation tends to use the highest percentage of its allocated amount.

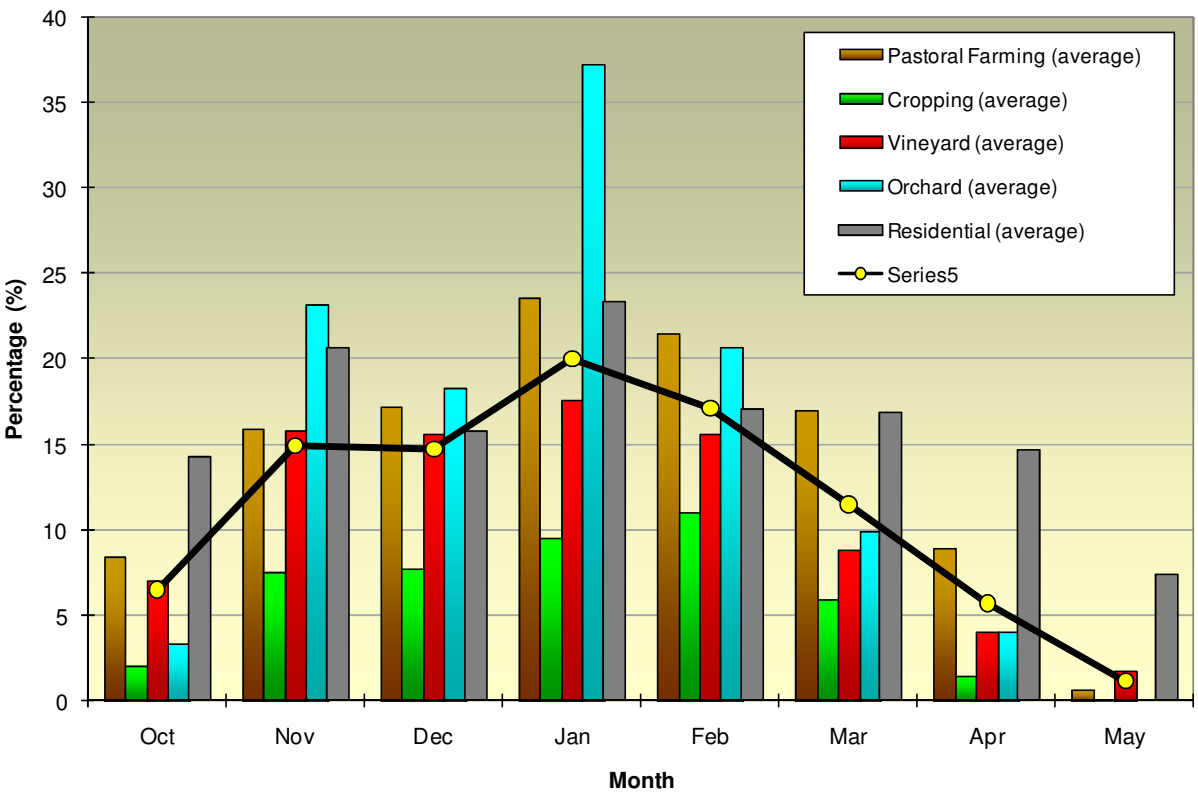

Figure 9-1: Overall Actual Water Use as Percentage of Allocation – by Landuse Type

The overall average water use is 9 percent for the Tutaekuri catchment and 18 percent for the Tukituki catchment.

9.1 Advantages and Shortcomings of Methodology

The methodology followed in this study has a number of pros and cons.

Advantages:

- The greatest advantage of the methodology used here is that the results are based on *actual* measured water use and abstraction rates. The dataset of metered data provides a picture of what is really happening with abstraction rates across the region.

- A percentage of actual water use compared to allocated amounts is able to be defined by catchment, landuse, and by the month of the irrigation season.

- The averaging of the abstraction and allocation rates accounts for the reality that many abstractions may be operating at once and taking more than the average allocation while at other times there may be fewer abstractions taking less than the average allocation.

- This investigation derived a daily average consented allocation (Table 4-1, Step 2) based on the *weekly consented volumes* (as defined by resource consent records). The previous work used the *consented maximum instantaneous abstraction rate*, which when totalled over a week is greater than the weekly consented allocation volume and leads to an over-estimation of the catchment-wide abstraction.

Shortcomings:

- The study is reliant on the quantity and quality of available data. The meter abstraction data is a relatively small sample of the total number of consented surface water abstractions. In terms of quality the meter dataset is variable; some abstractions are not consistently recorded at regular intervals (e.g. weekly) and there is only a year's worth of data for many sites. However, a number of meter records in the Ngaruroro catchment do go back to the 1990's.

- The derived abstraction rates for each catchment were applied as a constant over a month. In reality abstractions would not operate constantly, and are likely to take more than the 'average' abstraction for a few days then take no water for a period in response to rainfall or irrigation practices.

- Groundwater interactions were not investigated. Some of the catchments (e.g. Waipawa) experience large groundwater losses and gains. Although this is 'natural' and does need to be accounted for in the flow naturalisation process, abstractive uses (both groundwater and surface water) could impact on the magnitude of groundwater recharge (loss) from the rivers.

- Only consented abstractions were accounted for. Permitted activity water takes (i.e. 20 m^3/day for domestic and stock water use) could cumulatively be having an effect on river flow, particularly at times of low flow. Further investigation into the quantity of this in each catchment should be considered.

- No account was made for climate in the analyses. In times of reasonable rainfall there is likely to be very little abstraction occurring. The key time, however, in terms of the flow naturalisation

work is the low flow periods when no rain would have fallen for a period of time, or if it had then it is likely to be of insufficient quantity to ease the need for irrigation.

9.2 Summary

This study produced naturalised flow records for the Tutaekuri, Tukipo, Waipawa, Tukituki and Maraetotara rivers for the period 1 July 1969 to 30 June 2008. Data has been produced for the Porangahau River from 2000.

As further metering of abstractions occurs over time, the knowledge of the water resource and pressures upon it will increase, so that at a time in the future when the flow naturalisation process is repeated and extended there will be a wealth of data available to estimate the true volume of abstraction from the region's water resources.

10 Recommendations

The naturalised flow records developed here should be added to the HBRC hydrological database and appended to the previous naturalised datasets.

Metering of water abstractions has been invaluable in this study and will be of great benefit in further defining the state of region's water resource. As such, HBRC should continue to encourage the collection of water abstraction data as well as also encouraging the meter readers to consistently take regular readings (e.g. regular daily or weekly intervals) or to allow the data to be telemetered so that real-time naturalisation of the river flow can occur.

Targeted or intensive investigations could be considered in a particular catchment for one or two irrigations seasons to further define abstraction characteristics in the region.

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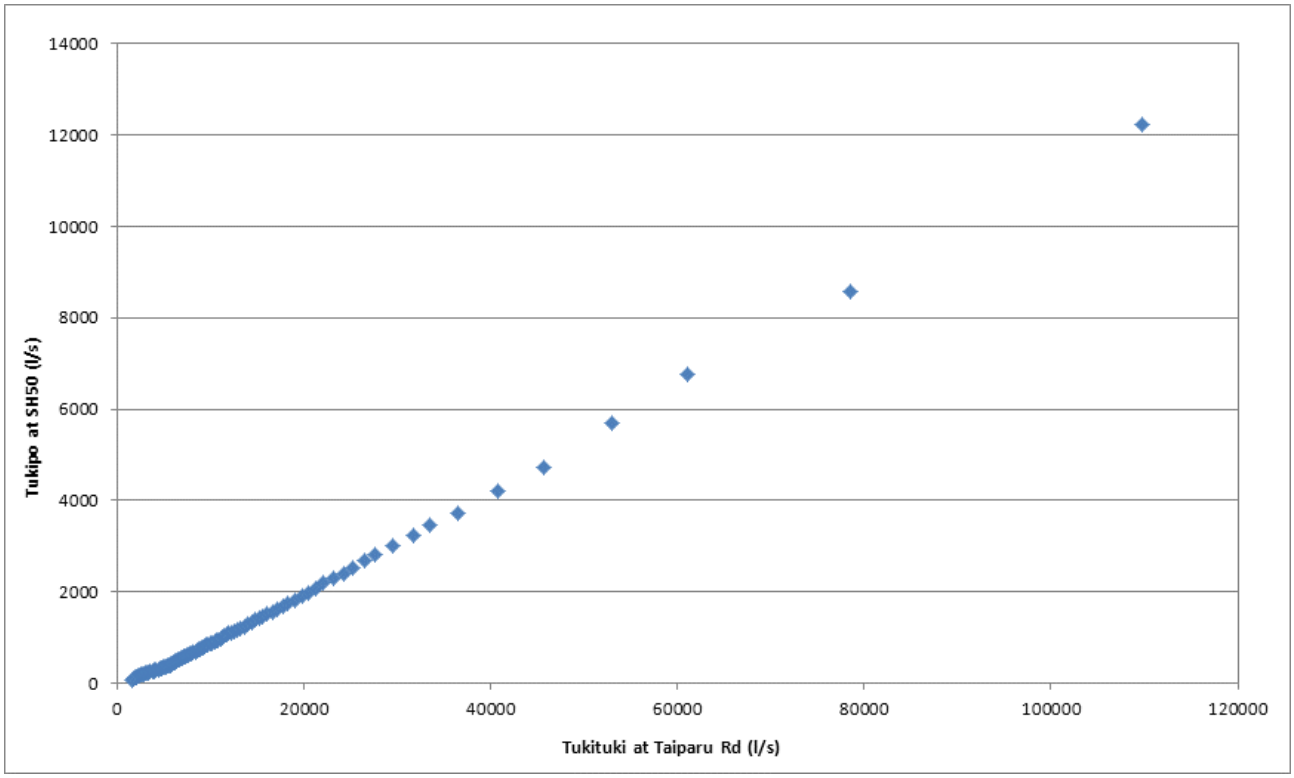
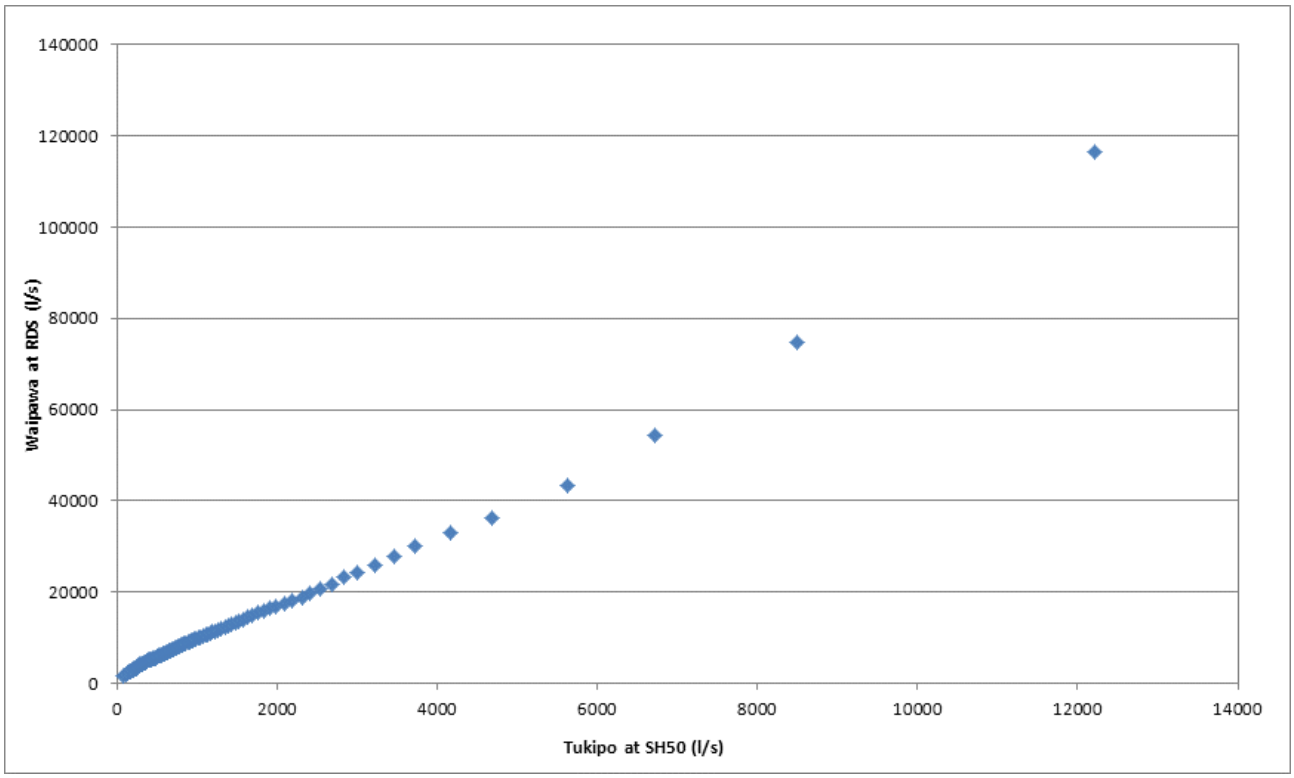
Appendix A

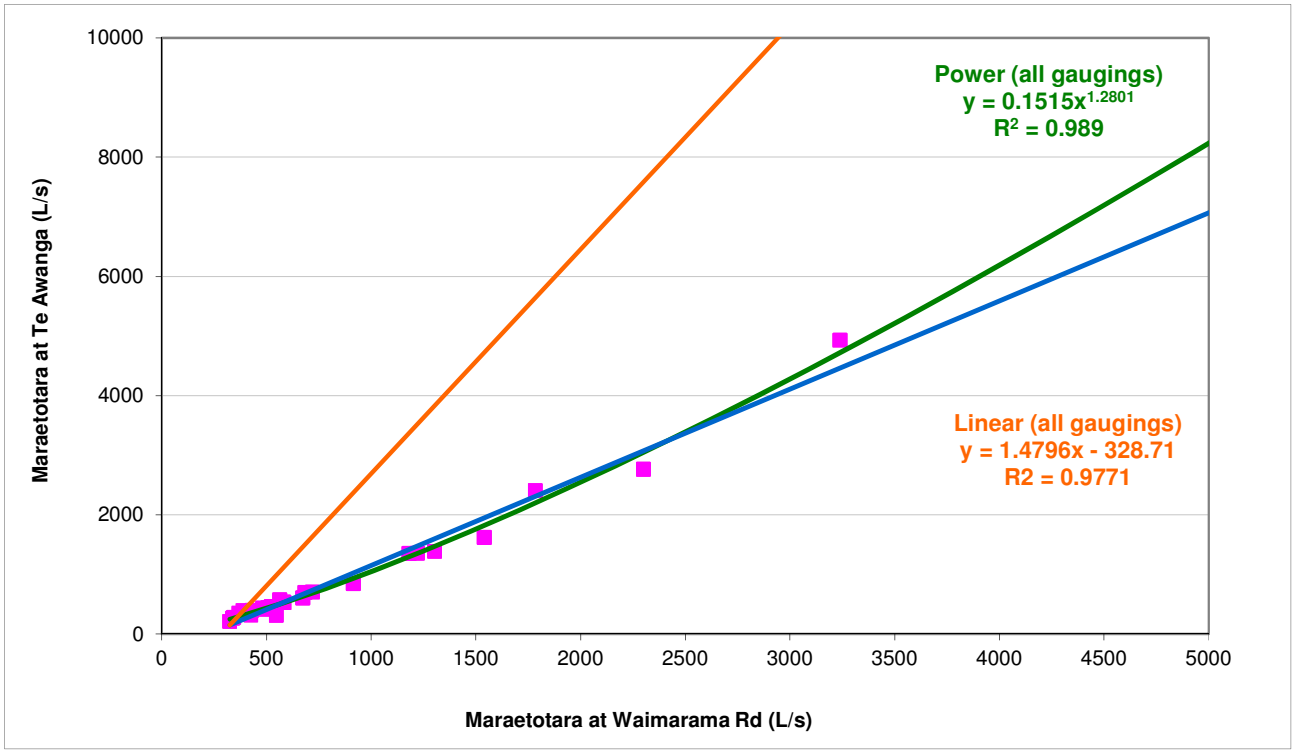
Correlations used in extending flow record at various sites



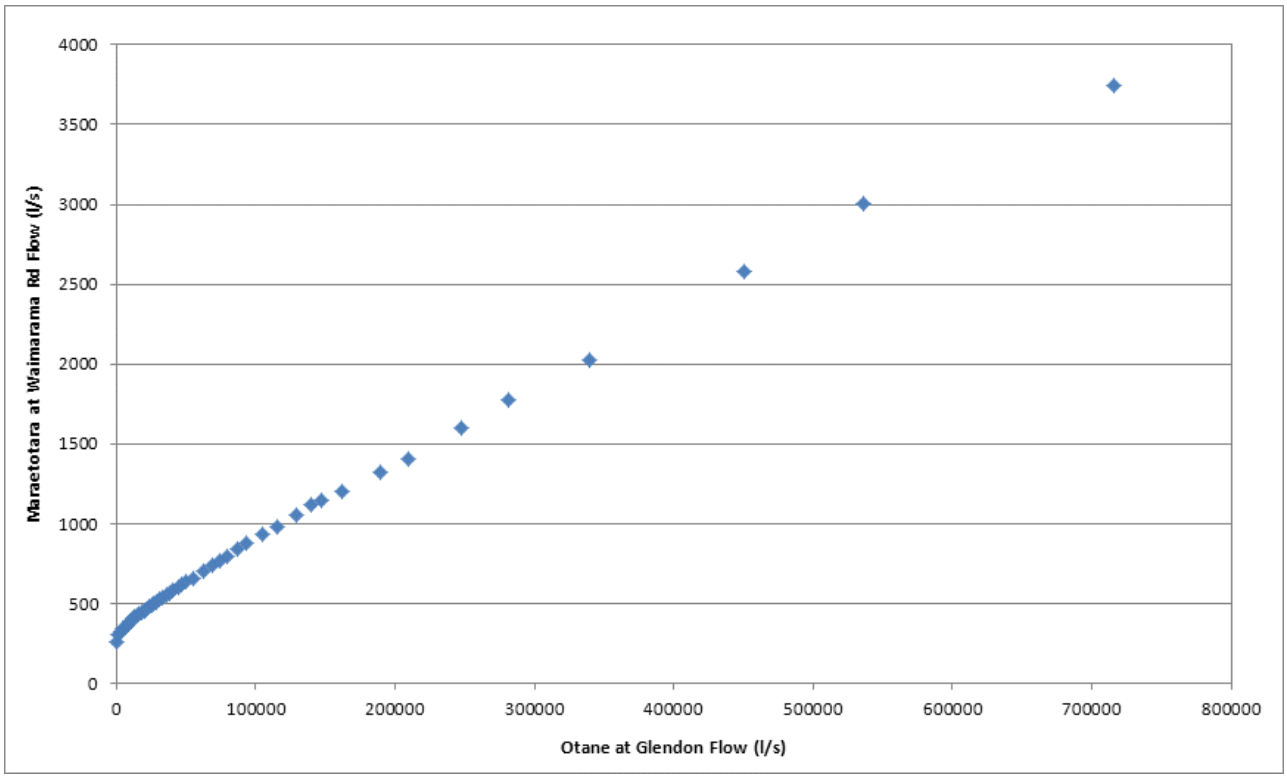
Tukipo at SH50 vs Tukituki at Tapairu Rd - Flow Exceedence Rating Relationship



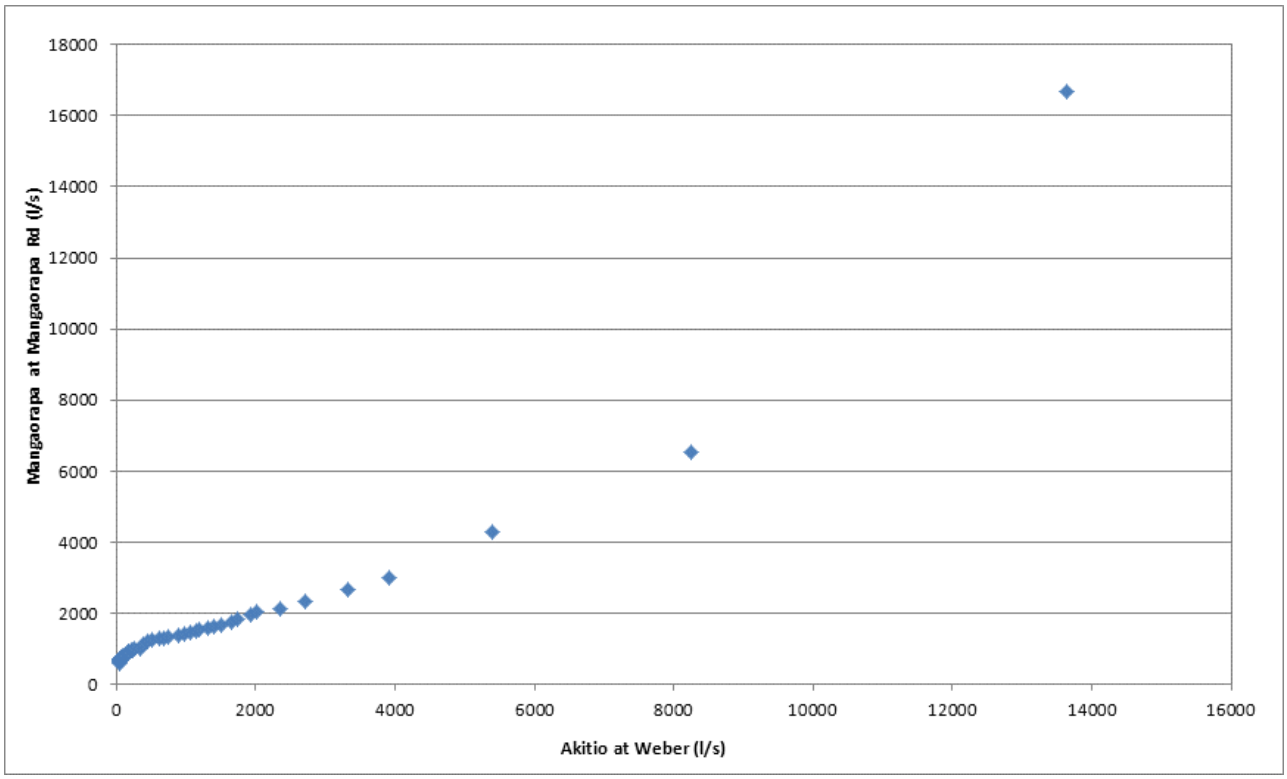
Tukipo at SH50 vs Waipawa at RDS - Flow Exceedence Rating Relationship



Maraetotara at Waimarama Rd vs Maraetotara at Te Awanga. Gauged flow relationship, combination of linear and power correlation used.



Maraetotara at Waimarama Rd vs Otane at Glendon - Flow Exceedence Rating Relationship



Akitio at Weber vs Mangaorapa at Mangaorapa Rd - Flow Exceedence Rating Relationship