Ngaruroro River High Flow Allocation
June to November Period

Prepared for Hawkes Bay Regional Council

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HAWKES BAY REGIONAL COUNCIL
Ngaruroro River High Flow Allocation - June to November Period

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1 Introduction

Water is a vital resource for New Zealand's recreation, economy, environmental values and health. Pressures on the freshwater resource are increasing with potential for the demand upon it to increase significantly over the next few decades.

The Hawkes Bay climate is such that there are periods of drought and high rainfall that make managing the freshwater resource a critical issue for the region.

With increasing pressure coming on the water resource of the region by activities such as horticulture, viticulture and dairy farming, practices such as harvesting river water at times of high flow are becoming an attractive water management option. There is potential for sustainable water harvesting for storage in times of higher river flows to provide water in times of water restrictions and low flows.

1.1 Background

The Ngaruroro River has been used as a water resource since the early 1970's (HBRC 2001). As the benefits of irrigation to the rural community have been realised the demand on the water resource has increased.

The river is a valuable source of water for irrigation in the Hawkes Bay region as well as being the main source of recharge for the Heretaunga Plains aquifer. It is highly regarded as a recreational resource for fishing, swimming and boating and is also valued by the hapu that live in the area as a food source and for its spiritual quality (HBRC 2001).

The Ngaruroro River is important both for its ability to supply water during frequent east coast droughts and as the major source of water for population centres and agriculture on the Heretaunga plains. The river is approximately 150 km in length and drains an area of more than 2,500 km^2. Its headwaters rise in the Kaimanawa Ranges and drain the eastern side of the North Island central plateau. As such it is not as prone to the intense short-lived droughts as the smaller east coast streams that rise in the lee of the main ranges.

Despite this, users of water from the river are still subject to restrictions in summer/autumn as low flows approach the regulatory minimum flow when abstractions must cease.

MWH (2008) completed an investigation into high flow allocation from the Ngaruroro River based on making such an allocation available in the May to October period.

1.1.1 MWH (2008) High Flow Allocation Investigation

The 2008 investigation into high flow allocation from the Ngaruroro River (MWH 2008) presented an overview of methods used by other Regional Councils throughout New Zealand and used these as guidance to develop a number of high flow allocation scenarios for the Ngaruroro River. Eight base scenarios were proposed, and this increased to 16 scenarios when a number of maximum allocation limits were trialled.

Initial ecological analyses reduced the number of scenarios to nine that did not adversely affect instream ecological values such as the FRE_3 statistic (the number of times per year that river flow exceeds 3 times the median flow).

Further ecological analysis and a Range of Variability (RVA) hydrological analysis resulted in four preferred high flow allocation methods for the Ngaruroro River between May and October.

1.2 Objective

MWH has been commissioned by Hawkes Bay Regional Council (HBRC) to investigate the potential for high flow water allocation to allow water harvesting from the Ngaruroro River during the winter and spring months (June to November) when typically the river flows are higher.
As detailed in Section 1.1.1, MWH (2008) has previously completed similar investigations.

The objective of this investigation is to model high flow allocation during the June to November period (as opposed to the May to October period in the 2008 work) and determine any effects on instream values. The four preferred high flow allocation scenarios from the 2008 investigation are reanalysed here, along with four additional scenarios developed in consultation with HBRC.

In conjunction with hydrological and ecological analyses of the Ngaruroro River flow the high flow allocation scenarios will be modelled to determine a sustainable flow above which high flow allocation could be made available without adversely impacting on instream ecology requirements and flow variability.

The 2008 investigation was carried using a naturalised flow dataset for the Ngaruroro River made of from two separately derived naturalised datasets from 1969 to 1996 (Opus 1997) and 1997 to 2008 (MWH 2008a). MWH (2010) updated the 1969 to 1996 dataset so that a continuous and consistent naturalised flow dataset for the Ngaruroro River is available from 1969 to 2008. The latest naturalised flow data (MWH 2010) has been used in this investigation.

1.3 High Flow Allocation and Water Harvesting

High flow, or supplementary, allocation provides access to water at times when river flows are higher and water is sufficiently abundant. High flow allocation is commonly provided to encourage water harvesting and storage.

1.4 Water Allocation

Figure 1-1 details a generalised picture of how high flow allocation could be managed within existing water allocation practices.

An instream minimum flow requirement is usually set that protects defined instream values such as a minimum amount of habitat. Consented abstraction of river flow ceases when river flow falls to this level. The minimum flow for the Ngaruroro River is based on instream habitat assessments and is set at 2.4 cubic metres per second (m^3/s).

The core allocation, or allocable volume, is defined as the difference between a prescribed management level and the minimum flow. The management level for the Ngaruroro River is set at the 95 percentile flow (Q_{95}) of the summer flow period (November to April). This is the flow that is exceeded 95 percent of the time.

The core allocable volume for the Ngaruroro River, as defined by the Regional Resource Management Plan (HBRC, 1996) is 956,189 cubic metres per week (m^3/week). This equates to a rate of 1.581 m^3/s.

The existing allocation regime of the Ngaruroro River allows all flow in excess of the allocable volume to remain in the river.

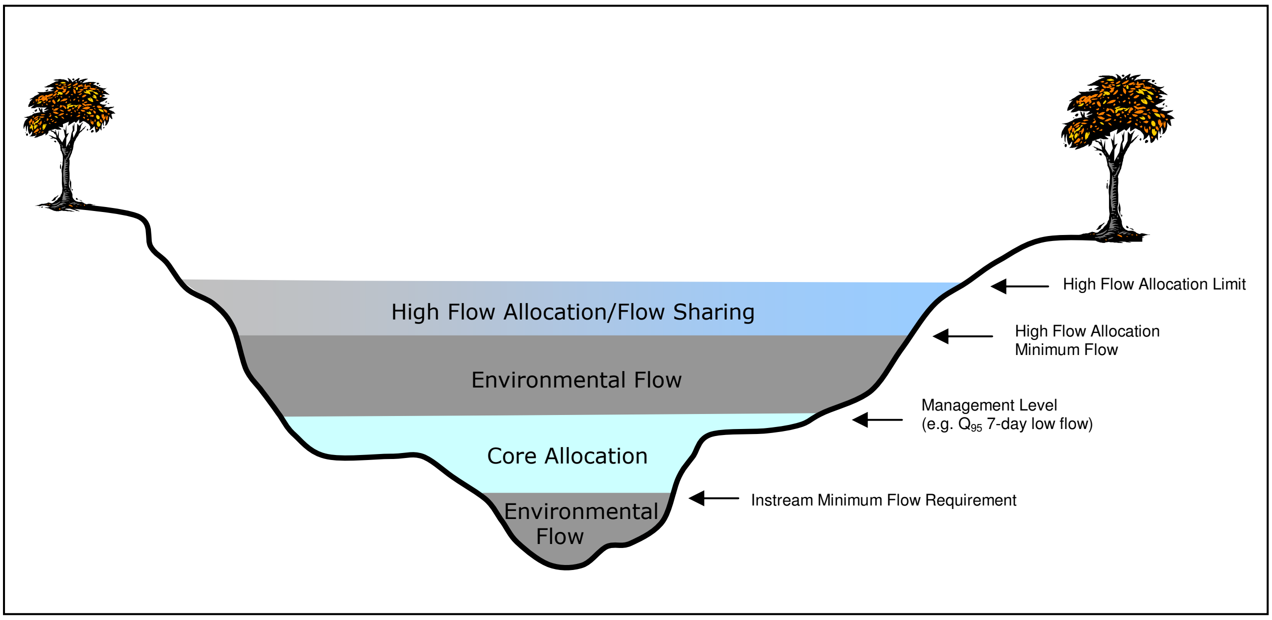

Figure 1-1: Idealised River Flow Allocation

The idea of high flow allocation or water harvesting is shown in Figure 1-1. A high flow allocation minimum flow is required so that water harvesting only occurs when river flow is above this level. A flow sharing approach for the high flow allocation (e.g. 50% allocated for abstraction, 50% remaining in river) would seek to maintain flow variability in the river and not unduly impact on ecological values such as flushing or disturbance flows that are essential to maintaining the instream ecosystem and channel structure.

High flow allocation should ideally occur in times of relatively higher river flows such as winter and spring so that harvesting of flow has only a small proportionate effect on reducing river flows.

1.4.1 Water Harvesting

Water harvesting is the practice of diverting a portion of river flows into a suitable storage for subsequent use during periods of reduced water availability. This enables utilisation of the available water resources for maximum productive benefit while reducing pressure on water resources during period of limited availability.

Water harvesting can be carried out in various ways:

- Setting higher minimum flows (above the core allocation) for category B or C water permits, where users accept a lower priority and security of supply. This ensures category A permits have access to the core allocation.
- Taking water during times of higher river flow during the irrigation months.
- Diverting water to storage over winter months, when demand is low and river flows are high, and to utilise the stored water to meet irrigation demand during summer that could otherwise not be met from the available flow allocation.
- Setting higher minimum flows to allow water abstraction for frost protection purposes.

2 High Flow Allocation at Regional Councils

A number of Regional Councils throughout New Zealand address high flow or supplementary allocation of surface water resources in their regional plans or water allocation plans.

A review of all Regional Council relevant regional plans was carried out by MWH (2008). Of the twelve regional councils and four unitary authorities of mainland New Zealand, eight have specific mention of high flow or supplementary water allocation from surface water resources in their planning documents:

- Environment Waikato
- Environment Bay of Plenty
- Horizons Regional Council
- Greater Wellington Regional Council
- Marlborough District Council
- Environment Canterbury
- Otago Regional Council
- Environment Southland

Reference should be made to MWH (2008) for detail of each Regional Council's approach to high flow or supplementary allocation. Table 2-1 provides a summary of the relevant high flow or supplementary allocation methods adopted by the regional councils (MWH 2008).

Table 2-1: High Flow Allocation - Regional Plan Summary

Council	Plan	Summary of High Flow/Supplementary Allocation
Environment Waikato	Proposed Waikato Regional Plan	Any supplementary allocation must not be contrary to objectives of Plan or only have minor adverse effects. A, B & C bands – no specific minimum flow levels for supplementary allocation given.
Environment BOP	Proposed Regional Water and Land Plan	Consider high flow allocations while protecting IMFR. No specific flow etc given
Horizons	Proposed One Plan	Two methods: i) when river flow greater than median flow and total supplementary take does not exceed 10% of the actual flow ii) where it can be shown that supplementary allocation will not increase frequency/duration of low flows, cause any adverse effects on waterbody values, or limit the ability for core allocations to be exercised.
Greater Wellington	Regional Freshwater Plan	Minimum flows for supplementary allocations detailed for main rivers in region. Supplementary allocation allowed when this flow is exceeded. Consent process to decide allocation limits
Marlborough District	Proposed Wairau/Awatere Resource Management Plan	Class C water permits available above the flow that is exceeded 80% of the time. No upper limit on C allocations. Example – 67% of flow above Q_{80} flow
Environment Canterbury	Natural Resources Regional Plan	B Block allocation. Additional allocation blocks can be provided
Otago Regional Council	Regional Plan: Water for Otago	Further Supplementary Allocation band. Minimum flow for supplementary allocation is the natural mean flow
Environment Southland	Proposed Regional Water Plan for Southland	Minimum flow for supplementary allocation is the natural mean flow

3 Previous Investigations and Policy for Ngaruroro River

Relevant catchment investigations and technical reports have been reviewed for the Ngaruroro River in terms of hydrology, ecology, water allocation and water quality. The Bibliography section of this document presents all technical reports reviewed but not referenced directly.

3.1 Ngaruroro River High Flow Allocation (2008)

MWH (2008) completed a report *Ngaruroro River High Flow Allocation* that investigated 16 high flow allocation scenarios for the Ngaruroro River. The investigations were based on the period of May to October being used for high flow allocation.

This current investigation reanalyses the four preferred high flow allocation scenarios from the 2008 work (and adds another four scenarios) using the recently updated and extended Ngaruroro River naturalised flow data record and changes the high flow allocation period to the June to November months.

3.2 Regional Resource Management Plan

Hawke's Bay Regional Resource Management Plan (RRMP) prescribes objectives and policies which define the ecological instream management and surface water quantity management objectives for the Ngaruroro River.

3.2.1 Ecological Instream Management Objectives for Ngaruroro River

The RRMP prescribes the following objectives and policies, which define the ecological instream management objectives for the Ngaruroro River.

Objective 25: Surface Water Quantity
The maintenance of water quantity of the rivers and lakes in order that it is suitable for sustaining aquatic ecosystems in catchments as a whole….while recognising the impact caused by climatic fluctuations in Hawke's Bay.

Objective 27: Surface Water Quality
The maintenance or enhancement of the water quality of rivers, lakes and wetlands in order that it is suitable for sustaining or improving aquatic ecosystems in catchments as a whole…

Objective 40: Surface Water Quantity
The maintenance of the water quality of specific rivers in order that the existing species and natural character are sustained…

Policy 71: Environmental Guidelines – Surface Water Quality
To manage the effects of activities affecting the quality of water in rivers…in accordance with the environmental guidelines set out below in Table 3-1.

The guidelines provided Table 3-1 apply when the river is at or below median flow, with the exception of suspended solids, which applies to all flow conditions.

Objective 41: Surface Water Quantity
The maintenance of water quantity of specific rivers in order that the existing aquatic species and the natural character are sustained…

In summary, the above objectives and policies seek to maintain or improve existing aquatic ecosystems (i.e.: the status quo) of the Ngaruroro River.

Table 3-1: Table 7 of the RRMP – Surface Water Quality Guidelines

Issue	Guideline
Temperature	The temperature of the water should be suitable for sustaining the aquatic habitat (i.e. not changed by more than 3℃, nor raised above 25℃)
Dissolved oxygen	The concentration of dissolved oxygen should exceed 80% of saturation concentration
Ammoniacal nitrogen	The concentration of ammoniacal ($N\text{-}NH_4^+$) should not exceed 0.1mg/l
Soluble reactive phosphorus	The concentration of soluble reactive phosphorus should not exceed 0.015 mg/l
Faecal coliforms (cfu/100ml)	50*, 100**, 150***
Suspended solids (mg/l)	10*, 25**, 25***

*Note: * Upstream of Fernhill Bridge;*
*** Between Fernhill Bridge and Expressway Bridge;*
**** Downstream of Expressway Bridge.*

3.2.2 Surface Water Quantity Management Objectives for Ngaruroro River

The RRMP prescribes the following objectives and policies pertaining to the management and use of surface water in the region and the Ngaruroro River.

Objective 25: Surface Water Quantity
The maintenance of the water quantity of the rivers and lakes in order that it is suitable for sustaining aquatic ecosystems in catchments as a whole and ensuring resource availability for a variety of purposes across the region, while recognising the impact caused by climatic fluctuations in Hawke's Bay.

Objective 26: Surface Water Quantity
The avoidance of any significant adverse effects of water takes, uses, damming or diversion on lawfully established activities in surface water bodies.

The demand for water in the Hawkes Bay region is rising, particularly as a result of increasing crop and pasture irrigation. Inefficient use of water exacerbates problems during summer droughts. The demand for surface water needs to be managed in a manner which ensures that water availability is maintained and water is allocated fairly, the impact of droughts is minimised, and economic development is not unnecessarily curtailed.

Policy 34: Role of Non-Regulatory Methods
(a) Education and co-ordination for encouraging efficient use of water, for example water harvesting, use of storage and consideration of alternative water supply, and avoiding wastage of water…...

Policy 35: Regulation – Water Allocation
(a) To manage the taking of water where the effects of that take may be more than minor.
(b) To manage the cumulative adverse effects of small takes, particularly in catchments:
- *(i) that are located in an area of low annual rainfall*
- *(ii) where the geology has a low storage capacity*
- *(iii) for which the location is such that there is a high potential for increased use.*

Policy 35 manages and controls water takes through the resource consent process.

Policy 37: Resource Allocation – Minimum Flows and Allocatable Volumes
(a) To manage takes from those rivers listed in Table 9 of this Plan in accordance with the minimum flows and associated allocatable volumes set out in that table.
(b) To establish minimum flows and allocatable volumes for additional rivers in accordance with the approach set out in Table 9 or as a result of research demonstrating that lower minimum flows or higher allocatable volumes are sustainable. Council will use the Plan Change procedure of the First Schedule of the RMA to introduce or change these.
(c) To ensure the protection of aquifer recharge from the effects of minimum flows.

Policy 37 establishes that takes from rivers will be managed in accordance with prescribed minimum flows and upper minimum flows and allocable volumes. Details for the Ngaruroro River are shown in Table 3-2 (sourced from RRMP Table 9). The minimum flow for the Ngaruroro River is 2.4 m^3/s as measured at the Fernhill Bridge monitoring site. The allocable volume is the difference between the summer (November to April) 7-day Q_{95} flow and the minimum flow (Policy 74).

Table 3-2: Ngaruroro River Minimum Flow and Allocable Volume

River	Minimum Flow Site	Minimum Flow (m^3/s)	Allocable Volume (m3/week)	Map Reference
Ngaruroro River	At Fernhill Bridge	2.4	956,189	V21:330729

Policy 39: Decision Making Criteria – Water Allocation
To allocate water from rivers in accordance with the following approach:
(a) The water requirement for each resource consent applicant will be determined on the basis of reasonable needs and the efficiency of end use, requiring an applicant to determine how much water is required for their activity (for irrigation takes, see also Policy 42).
(b) Where the demand for water within a stream management zone11 is greater than the allocatable volume as a result of a consent application for a new activity, a consent will not be issued except where it can be considered under (d)……

…..(d) Water may be allocated over and above the allocatable volume, subject to a substantially higher cut-off level than that specified in Table 9 provided that any such additional allocations will not have any adverse effect on other lawfully established activities, nor any other significant adverse environmental effect and assuming allocation is subject to the implementation and/or consideration of (a), (b) and (c).

Policy 39 establishes the overall approach for the allocation of surface water. This policy recognises that the type of water management required for the region's surface water bodies is variable. As such, Policy 39 sets out that HBRC can allow for periods when water can be allocated over the allocatable volumes (e.g. for water harvesting purposes). The ecological protection of the river, including the maintenance of a natural "flushing" effect is the baseline consideration for any allocations which are made under this scenario.

Objective 41
The maintenance of the water quantity of specific rivers in order that the existing aquatic species and the natural character are sustained, while providing for resource availability for a variety of purposes, including groundwater recharge

Policy 73: Environmental Guidelines – Surface Water Quantity
(a) To sustain aquatic ecosystems by establishing a minimum flow in a river as that level which will maintain the existing ecosystem.

Policy 74: Implementation of Environmental Guidelines – Surface Water Quantity
(a) Resource Allocation: To define the allocatable volume as being the difference between the summer 7-day Q_{95} and the minimum flow.

4 Existing Ngaruroro River Hydrology

4.1 Data

Flow data for the Ngaruroro River is collected at a number of sites along its length. The Ngaruroro River at Fernhill site is the relevant site for this investigation as detailed in Table 4-1.

Table 4-1: Ngaruroro River Flow Data

Site	Data Starts	Data Ends	Map Reference
Ngaruroro River at Fernhill	1952	2010	V21:330729
Ngaruroro River at Fernhill naturalised flow	July 1969	July 2008	V21:330729

The minimum flow for the Ngaruroro River (as set in the RRMP at 2.4 m^3/s) is monitored at the Fernhill site. For the purposes of this study and investigating high flow allocation, the Fernhill site is retained as the key measurement/regulation point on the river.

Although the Fernhill site is the low flow monitoring site for the Ngaruroro River it is actually very difficult to maintain a continuous flow record due to the regularly changing nature of the river bed. As such, a rating relationship to convert the measured water level to flow cannot be maintained.

A study by MWH (2010) produced a naturalised flow record for the Ngaruroro River at Fernhill (Table 4-1) that represents the natural river flow before any abstractions occur.

As the Fernhill site is used as the regulatory monitoring site, it is logical that a flow series at this location is used to analyse and model potential high flow allocation.

The Ngaruroro at Fernhill naturalised flow series is used for all analyses and modelling in this study. The naturalised flow series is ideal as it is not affected by abstractions. As this study is investigating the potential for high flow allocation in the winter/spring months of June to November it is assumed that any abstraction (including the artificial recharge take) occurring in this period will be small in comparison to the summer irrigation season, and will be only a small, proportion of the higher winter-spring flows. Therefore, the naturalised flow series is considered to adequately represent the river flow between June and November.

4.2 Flow Statistics

A number of hydrological statistics have been derived from the naturalised Ngaruroro at Fernhill flow record and presented in Table 4-2. Statistics derived from the June to November months as well as the entire data record are presented. Data is used for the full years of record between 1970 and 2007.

The statistics are recalculated after modelling various high flow allocation scenarios (Section 5) and compared to those tabled here.

Table 4-2: Ngaruroro at Fernhill Naturalised Flow Statistics (m^3/s), 1970-2007

Period	Minimum	Median	Mean	Maximum	Q_{80}	Q_{90}	Q_{95}
June to November	2.5	36	59	1426	19.5	14.6	10.2
Entire record	0.3	24	40	1642	9.6	7.1	5.3

The Q_{95} flow value is that which is exceeded 95% of the time. Similarly the Q_{80} and Q_{90} are the flows that are exceeded 80% and 90% of the time respectively.

The June to November period, being the winter and spring months, has higher flows overall - the exception being the maximum recorded flow. The median and mean flows for the June to November period are around 1.5 times greater than those of the entire record. The low flow statistics of Q_{80}, Q_{90} and Q_{95} are approximately twice the magnitude during the June to November period.

Hydrological statistics describing the variability of the Ngaruroro River naturalised flow record are detailed in Table 4-3, Figure 4-1 and Figure 4-2.

A method of describing the frequency that river biota are disturbed by flood flows is to calculate the FRE_3. That is the number of times per year that the flow exceeds three times the median flow (Clausen and Biggs, 1996). The FRE_3 value for the Ngaruroro River at Fernhill (entire record) is 71 m^3/s. This concept is discussed further in Section 7.

Table 4-3 details the frequency of occurrence of FRE_3 flows for the naturalised Ngaruroro River flow at Fernhill. FRE_3 values are presented on an annual basis for the June to November period and the entire year (January to December).

Table 4-3: Ngaruroro River Naturalised Number of Flow FRE_3 Occurrences

Year	Jun-Nov	Jan-Dec	Year	Jun-Nov	Jan-Dec	Year	Jun-Nov	Jan-Dec
1970	9	13	1983	7	9	1996	5	12
1971	16	22	1984	3	4	1997	9	10
1972	6	8	1985	5	7	1998	9	10
1973	8	9	1986	4	7	1999	7	11
1974	10	14	1987	5	9	2000	6	8
1975	10	12	1988	4	7	2001	5	10
1976	10	14	1989	9	12	2002	6	11
1977	6	7	1990	2	3	2003	6	10
1978	8	10	1991	2	5	2004	7	11
1979	9	12	1992	8	9	2005	6	12
1980	6	12	1993	1	4	2006	5	10
1981	15	18	1994	7	7	2007	8	9
1982	3	5	1995	6	9			
						Average	**7**	**10**
						Total	**255**	**369**
						Frequency (days)	**27**	**38**

The majority of FRE_3 events (approximately 70%) occur in the June to November period with an average of seven events (compared to 10 for entire year). The average frequency of FRE_3 events is one every 27 days during June to November, as opposed to one every 38 days over the entire year.

Figure 4-1 details the flow hydrograph for the naturalised Ngaruroro at Fernhill record in comparison to the FRE_3 magnitude. The red trace of the hydrograph identifies the June to November period for each year. It is clearly evident that there are more frequent FRE_3 events during this period compared to the remainder of the year (December to May).

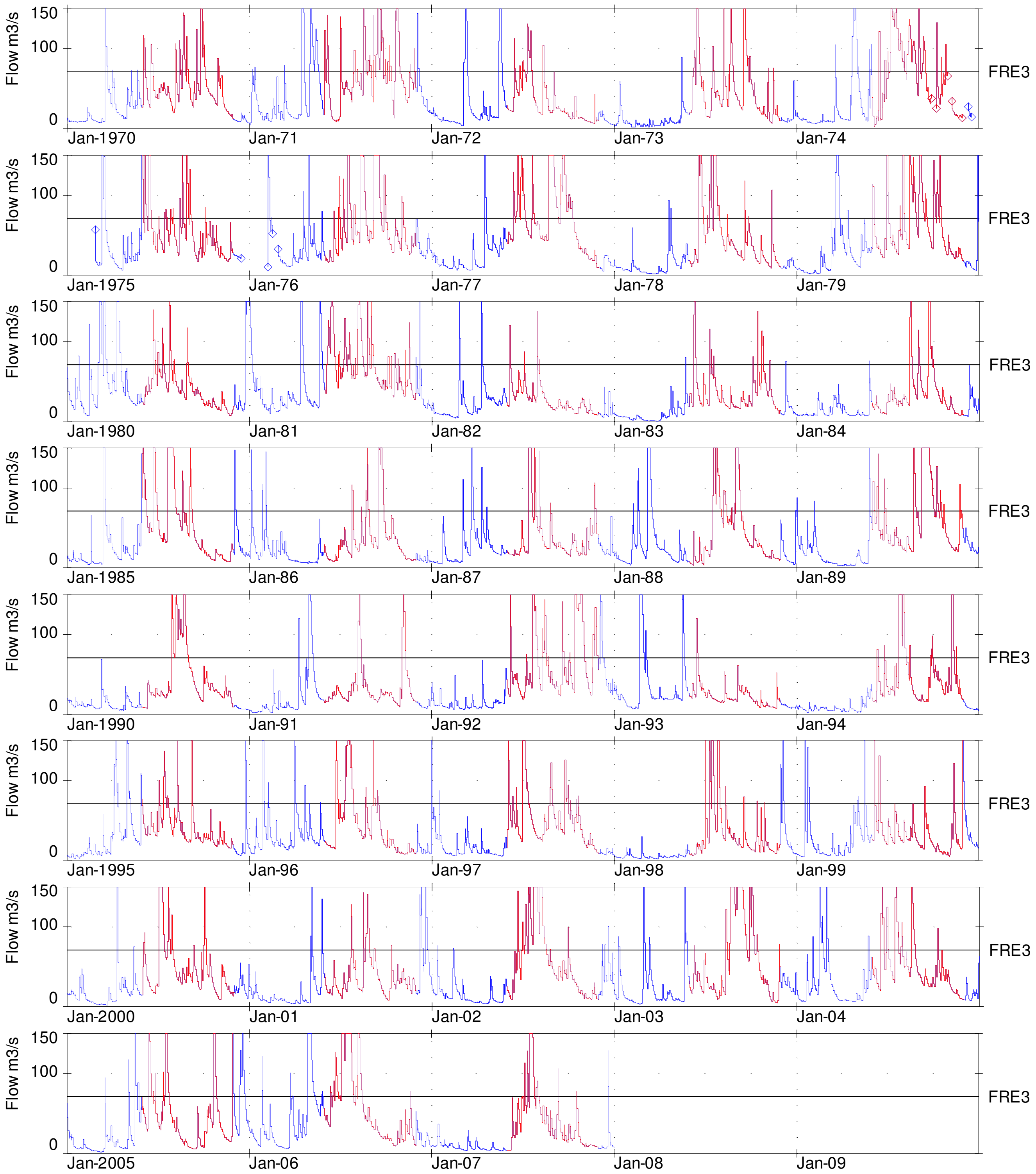

Figure 4-1: Naturalised Ngaruroro at Fernhill Flow Hydrograph and FRE_3

Figure 4-2 shows the flow duration and distribution for the naturalised Ngaruroro River flow at Fernhill from 1970 to 2007. The bold black trace details the entire record (i.e. January to December). The blue trace is the flow for only the June to November period of each year. The amount of time spent at or above a given flow is greater for the June to November period. For example, the entire flow record (January to December) is great than 15 m^3/s for 70% of the time, while in the June to November period the corresponding flow is 24 m^3/s.

The red trace on Figure 4-2 details the summer/irrigation period of December to May. More time is spent here at lower flows compared to the other periods.

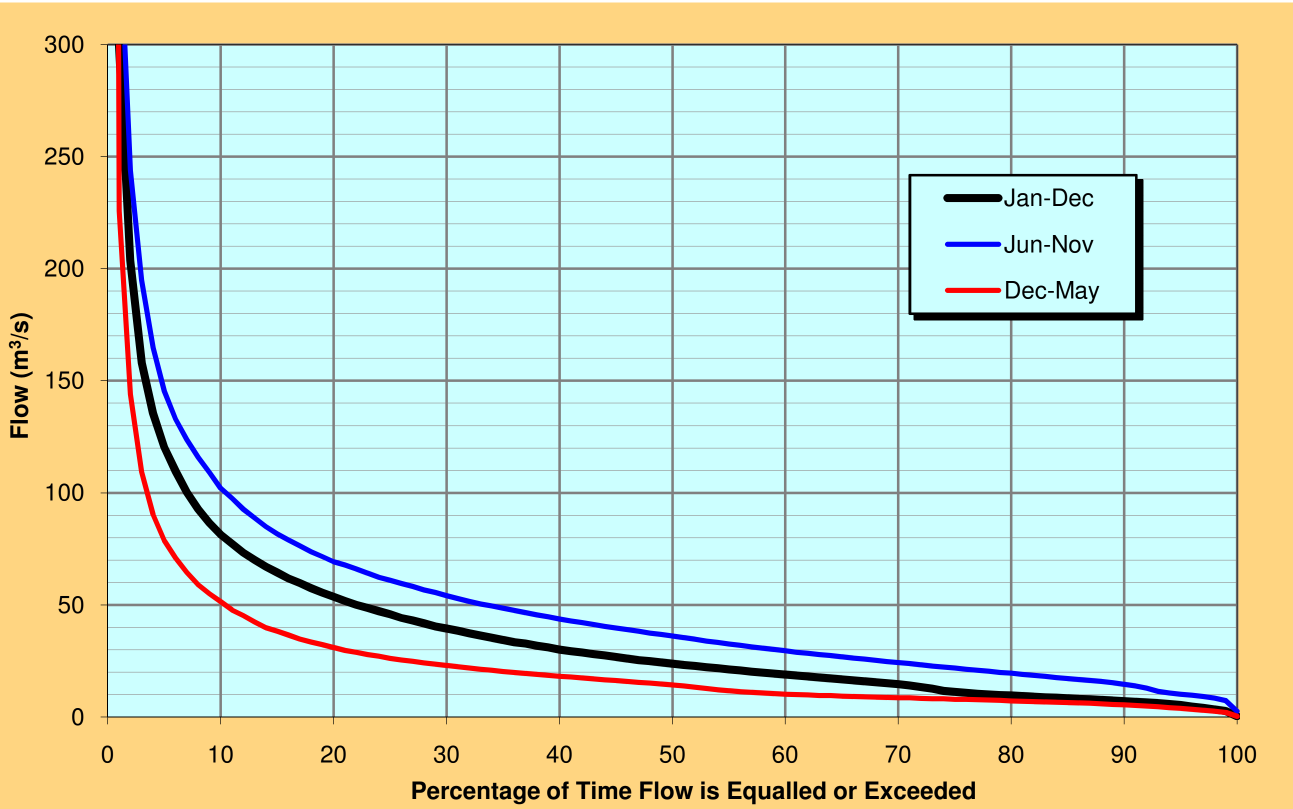

Figure 4-2: Naturalised Ngaruroro at Fernhill Flow Duration (1970-2007)

5 High Flow Allocation Scenarios

MWH (2008) developed a number of high flow allocation scenarios for the Ngaruroro River. The scenarios included those adopted at other Regional Council's within New Zealand. The scenarios were modelled with the Ngaruroro at Fernhill naturalised flow record only available between 1970 and 1995 (the naturalised flow record was not extended until after the 2008 work) to ascertain the impacts the allocation regimes would have on the river flow.

MWH (2008) explains the 16 allocation scenarios used and how they were derived. Four allocation scenarios were recommended as possible regimes for high flow allocation from the Ngaruroro River, which were based on the mean flow as a cut-off point for high flow abstraction. These four scenarios are adopted here and an additional four scenarios based on the median flow are added, as detailed in Table 5-1.

MWH (2008) found that modelling the scenarios without a maximum abstraction cap allowed for very large abstractions during flood events. The modelling process would assume that all allocation was abstracted which resulted in a residual river flow with flood peaks and freshes dramatically diminished. This is unrealistic, not only because of the sheer volume modelled as being abstracted, but also because in many high river flow events the water becomes very turbid and silt laden and this becomes a physical limitation on water harvesting. Sediment laden water has adverse effects on pumping equipment and can lead to sediment deposition behind dams if diverted there.

Maximum allocation limits of 2 m^3/s and 5 m^3/s have been imposed. Currently the flow allocation limit for the Ngaruroro River equates to 1.581 m^3/s (956,189 m^3/week) (MWH 2008).

The flow threshold values used (median and mean) are derived from the entire naturalised flow record for the Ngaruroro River at Fernhill - not just the June to November period.

Table 5-1: High Flow Allocation Scenarios

Scenario	Description
Method 1	If river flow > MEAN, then 50% of flow above the MEAN allocated **- up to a maximum of 2 m^3/s**
Method 2	If river flow > MEAN, then 50% of flow above the MEAN allocated **- up to a maximum of 5 m^3/s**
Method 3	If river flow > MEAN, then 33% of flow above the MEAN allocated **- up to a maximum of 2 m^3/s**
Method 4	If river flow > MEAN, then 33% of flow above the MEAN allocated **- up to a maximum of 5 m^3/s**
Method 5	If river flow > MEDIAN, then 50% of flow above the MEDIAN allocated **- up to a maximum of 2 m^3/s**
Method 6	If river flow > MEDIAN, then 50% of flow above the MEDIAN allocated **- up to a maximum of 5 m^3/s**
Method 7	If river flow > MEDIAN, then 33% of flow above the MEDIAN allocated **- up to a maximum of 2 m^3/s**
Method 8	If river flow > MEDIAN, then 33% of flow above the MEDIAN allocated **- up to a maximum of 5 m^3/s**

Note - Median and mean are from entire period of flow record

6 Hydrological Consideration of High Flow Allocation Scenarios

6.1 Comparison of Hydrological Statistics

Table 6-1 details some basic hydrological statistics for the residual/altered Ngaruroro River flow after high flow allocation for each of the scenarios. All results are for the June to November months between 1970 and 2007 (inclusive).

The magnitude of changes as a percentage (% Δ) of the naturalised flow record are detailed for the median, mean and maximum values for each method.

Table 6-1: Ngaruroro River Residual Flow Statistics (m^3/s) for High Flow Allocation Scenarios (June - November)

Flow Scenario	Flow Statistic									
	Minimum	Q_{95}	Q_{90}	Q_{80}	Median	% Δ	Mean	% Δ	Maximum	% Δ
Naturalised	2.5	10.2	14.6	19.5	36		54		1426	
Method 1	2.5	10.2	14.6	19.4	36	*0*	53	*2*	1424	*0.1*
Method 2	2.5	10.2	14.6	19.4	36	*0*	52	*4*	1421	*0.4*
Method 3	2.5	10.2	14.6	19.4	36	*0*	53	*2*	1424	*0.1*
Method 4	2.5	10.2	14.6	19.4	36	*0*	52	*4*	1421	*0.4*
Method 5	2.5	10.3	14.7	19.4	34	*5.6*	53	*2*	1424	*0.1*
Method 6	2.5	10.2	14.7	19.4	31	*14*	51	*6*	1421	*0.4*
Method 7	2.5	10.2	14.6	19.4	34	*5.6*	53	*2*	1424	*0.1*
Method 8	2.5	10.2	14.6	19.4	32	*11*	51	*6*	1421	*0.4*

There are virtually no changes to the low flow statistics (minimum, Q_{80}, Q_{90}, Q_{95}). Only Methods 5 and 6 show very small (0.1 m^3/s) changes.

Figure 6-1 shows the flow distributions for the altered Ngaruroro River flow after the high flow allocation methods have been modelled. The FRE_3 value has been over-plotted.

Figure 6-2 provides a closer view of the 10% to 70% range where most of the variation away from the original naturalised flow data occurs.

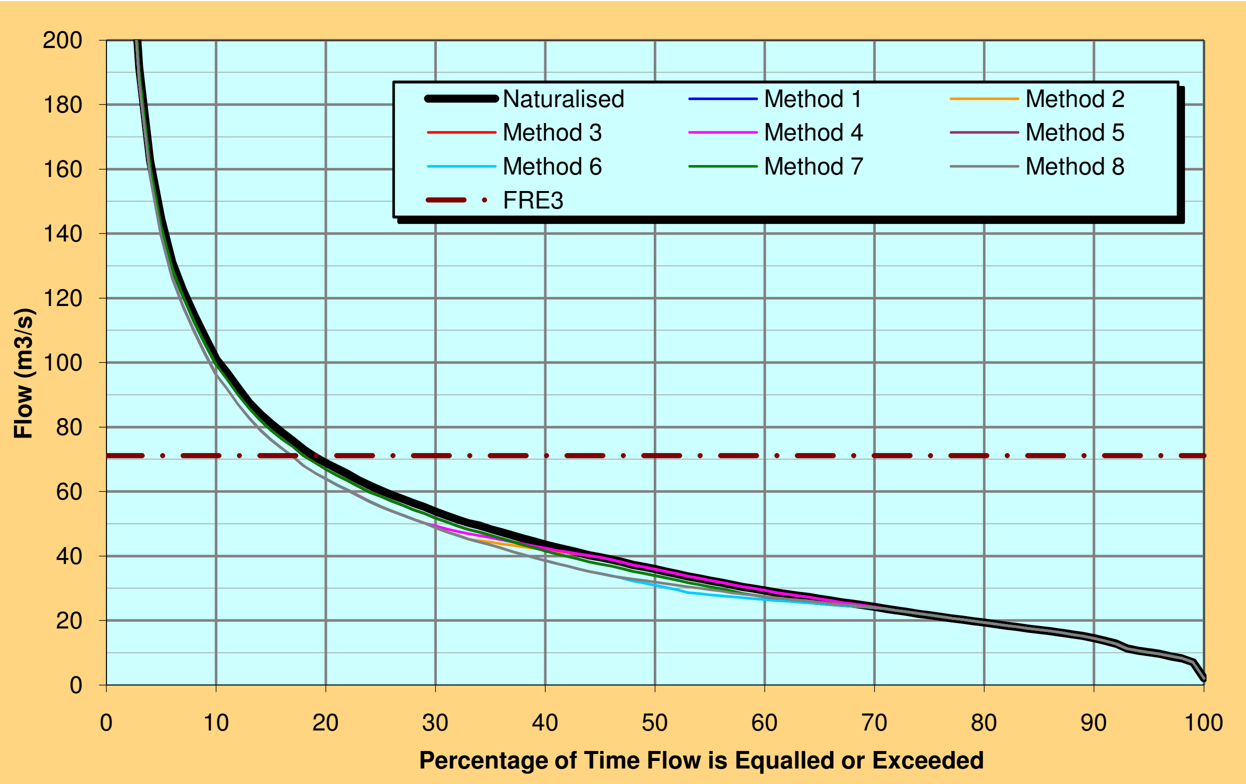

Figure 6-1: High Flow Allocation Methods Flow Distribution – June to November

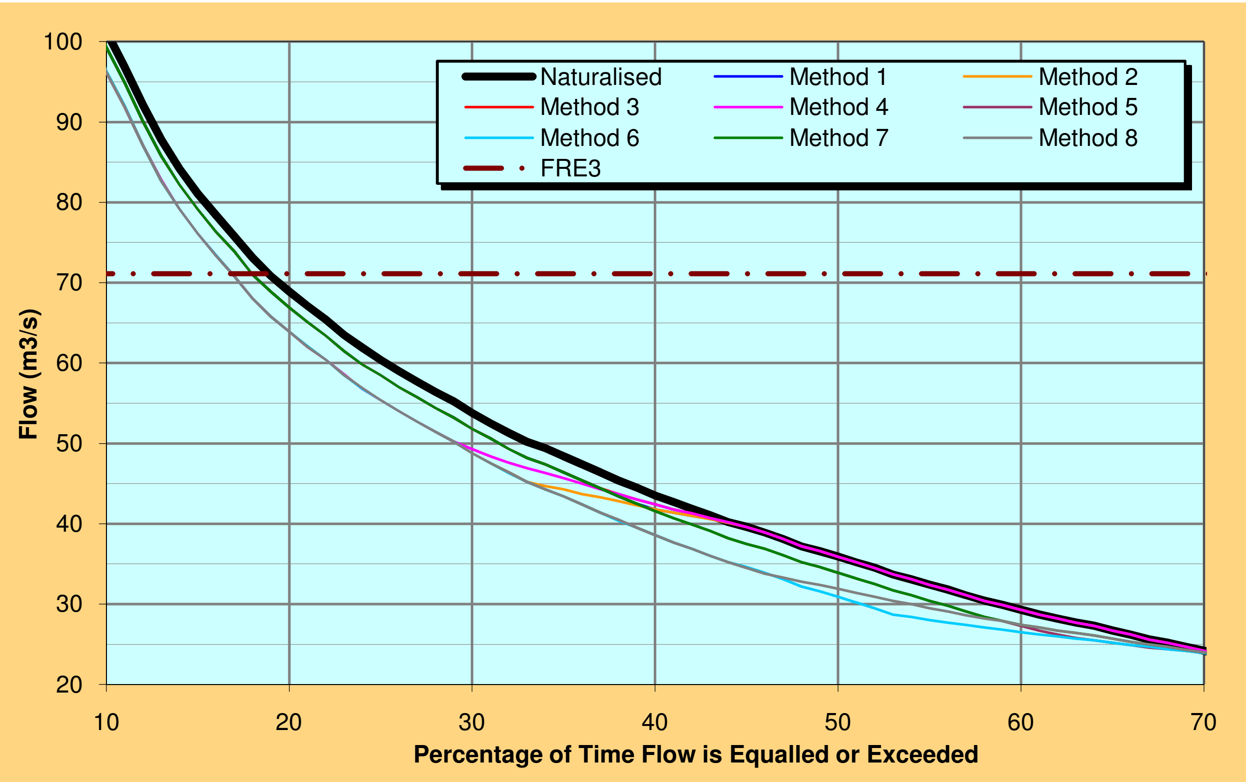

Figure 6-2: Zoom-in of High Flow Allocation Methods Flow Distribution – June to November

6.2 Allocable Volumes under High Flow Allocation Scenarios

The modelling of the eight high flow allocation methods on the naturalised Ngaruroro River at Fernhill flow record is used to derive the volume of water that is available for abstraction under each allocation regime.

Table 6-2 details the average weekly volume (m^3/week) and the equivalent instantaneous rate (m^3/s) for each of the allocation method scenarios for the June to November months between 1970 and 2007.

Of the high flow allocation scenarios, Methods 1 and 3 show the lowest allocable volume available with an average of around 500,000 m^3/week (0.823 m^3/s) for the June to November period. Both these methods have a maximum allocation of 2 m^3/s.

All allocation methods with a 2 m^3/s allocation limit (Methods 1, 3, 5 and 7) provide less than the core allocation – ranging from 488,275 to 809,424 m^3/week (0.807 to 1.338 m^3/s). The current core allocation from the Ngaruroro River is 956,189 m^3/week (1.581 m^3/s).

All those allocation methods with a 5 m^3/s allocation limit (Methods 2, 4, 6 and 8) provide more allocable volume than the core allocation – ranging from 1,080,576 to 1,856,837 m^3/week (1.787 to 3.070 m^3/s).

Tables of the average weekly allocable volumes for all months and years of record for each Method are contained in Appendix A.

Table 6-2: High Flow Allocation Scenarios Average Allocable Volume (m^3/week and equivalent m^3/s) 1970-2007

Allocation Method	June		July		August		September		October		November		Mean	
	(m^3/wk)	*(m^3/s)*	*(m^3/wk)*	*(m^3/s)*	*(m^3/wk)*	*(m^3/s)*	*(m^3/wk)*	*(m^3/s)*	*(m^3/wk)*	*(m^3/s)*	*(m^3/wk)*	*(m^3/s)*	*(m^3/wk)*	*(m^3/s)*
Method 1	474768	0.785	729389	1.206	724550	1.198	494122	0.817	401587	0.664	189302	0.313	502286	0.831
Method 2	1084406	1.793	1721866	2.847	1671667	2.764	1146701	1.896	898128	1.485	423360	0.700	1157688	1.914
Method 3	459648	0.760	715478	1.183	705197	1.166	481421	0.796	385862	0.638	182045	0.301	488275	0.807
Method 4	1010016	1.670	1631146	2.697	1559779	2.579	1077754	1.782	821923	1.359	382838	0.633	1080576	1.787
Method 5	760234	1.257	1025136	1.695	1016669	1.681	866074	1.432	756000	1.250	432432	0.715	809424	1.338
Method 6	1766621	2.921	2406499	3.979	2384726	3.943	1966205	3.251	1695254	2.803	921715	1.524	1856837	3.070
Method 7	742090	1.227	1002758	1.658	993686	1.643	835834	1.382	728784	1.205	407635	0.674	785131	1.298
Method 8	1653523	2.734	2286144	3.780	2273443	3.759	1816214	3.003	1552522	2.567	816480	1.350	1733054	2.866

7 Ecological Consideration of Scenarios

7.1 FRE_3

The FRE_3 statistic is a measure of flow variability, being the number of times per year the flow exceeds three times the median flow.

The FRE_3 statistic incorporates both a frequency and intensity component (MfE 1998), and its application in New Zealand rivers has shown close correlation with instream biological (benthic) variables, such as periphyton and macroinvertebrate community structure (Clausen & Biggs 1997).

The FRE_3 method has been used here as the ecological basis for the broad assessment of biological consequences of all eight high flow allocation scenarios.

7.1.1 Biological Relevance

Flood frequency is of biological relevance primarily by provision of an important flushing function, thereby regulating water quality parameters and limiting periphyton accrual by sloughing of excessive periphyton growth.

The percentage of change from the naturalised FRE_3 score to the altered flow regime FRE_3 score provides a guide as to the likely impact to instream biological communities from the flow regime change.

Two key theories underlie this assumption:

i. Benthic communities are assembled according to the existing flow regime, and ‘significant’ changes in the flow regime are likely to result in significant changes to the biological composition of those communities.
ii. Benthic communities provide primary (periphyton) and secondary (macroinvertebrates) energy production functions, and changes in the abundance or diversity of these organisms can have wider reaching responses to production and energy flux in the aquatic environment.

7.1.2 Analysis of Allocation Method FRE_3 Values

Each of the allocation methods have been assessed for percentage change in the frequency and intensity components of the FRE_3 statistic. A threshold FRE_3 score of ≤10 percent change has been applied to each allocation option FRE_3 statistic to limit the potential impact to benthic communities, and therefore the impact to the wider aquatic environment.

Results of the assessments are presented in Table 7-1. All allocation methods show less than 10 percent change in mean FRE_3 value, meaning no scenarios are to be discarded from the pool of high flow allocation options for the Ngaruroro River.

All eight high flow allocation methods are carried forward for further analysis.

Table 7-1: Analysis of Allocation Method FRE_3 Occurrence (June to November, 1970-2007)

Allocation Method	Mean	% Change Mean	Total	% Change Total	Freq (days)	% Change Freq	Method supported based on <10% Change Criteria?
Naturalised	**6.7**		**255**		**27**		
Method 1	6.5	3	247	3.1	28	-3.2	Yes
Method 2	6.2	7.5	237	7.1	29	-7.6	Yes
Method 3	6.5	3	247	3.1	28	-3.2	Yes
Method 4	6.3	6	239	6.3	29	-6.7	Yes
Method 5	6.5	3	248	2.8	28	-2.8	Yes
Method 6	6.2	7.5	236	7.5	29	-8.1	Yes
Method 7	6.5	3	248	2.7	28	-2.8	Yes
Method 8	6.2	7.5	237	7.1	29	-7.6	Yes

7.2 Analysis of Methods against Instream Flow Requirements

The HBRC objectives and policies set out in the RRMP seek to maintain or improve existing aquatic ecosystems. Any high flow allocation regime needs to be set in the context of these instream management objectives and policies. There are three principle components of a flow regime requirement for ecological values (MfE 1998), namely:

- Flow variability
- A minimum flow for water quality
- A minimum flow for habitat requirements

Each of the eight high flow allocation methods is discussed against these ecological requirements.

7.2.1 Flow Variability

As discussed above it is recommended that in order to maintain instream ecological values, the mean FRE_3 value for the Ngaruroro River shall be changed by less than ten percent of the naturalised value. On this basis nine allocation methods are supported as potential regimes under which acceptable flow variability can be maintained.

Figure 7-1 presents these allocation methods in numerical order according to extent of change in FRE_3 value, from least to greatest percent change in mean value.

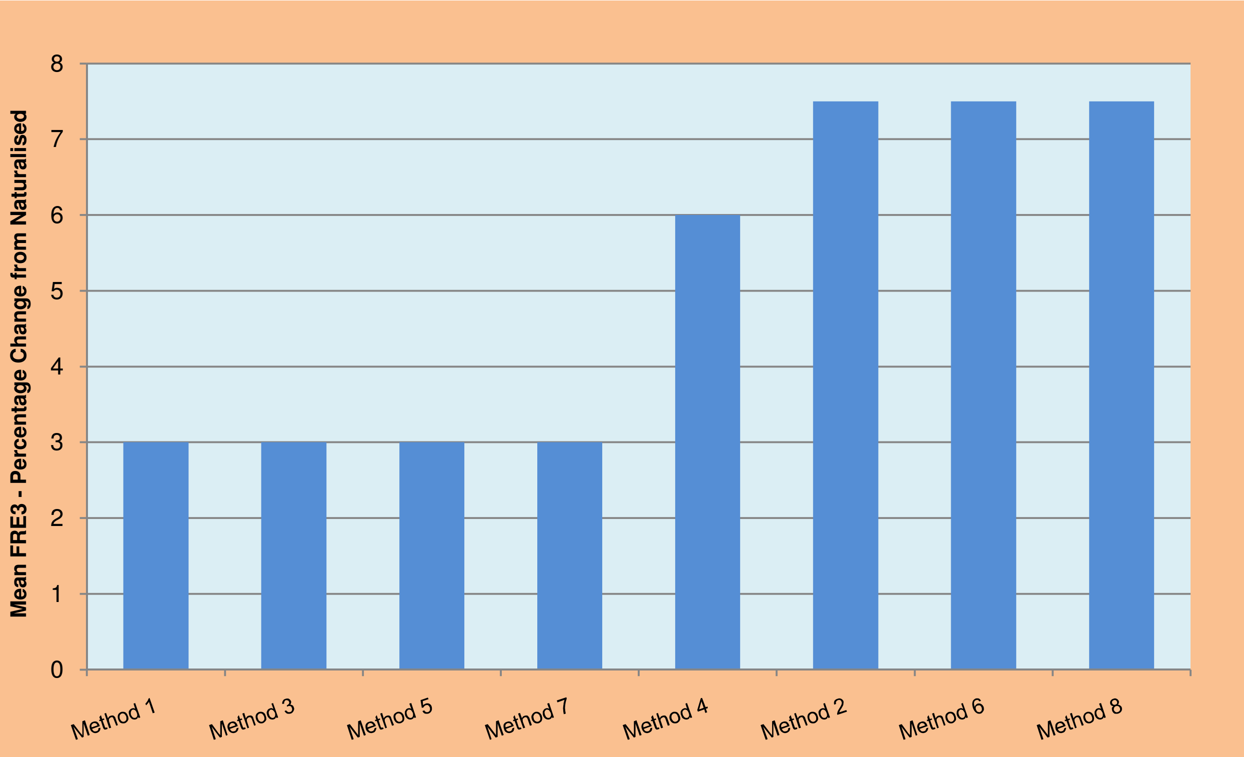

Figure 7-1: Percentage Change from Naturalised FRE3 Value for Allocation Methods

Under the naturalised flow regime, flows three times the median flow (biologically significant) occur on average once every 27 days (June to November). The frequency of biologically significant flood events has particular significance to the duration of periphyton accrual periods and maintenance of acceptable water quality (water quality is discussed further in Section 7.2.2).

Freshes can also be a functional requirement for selected fish species, which rely on pulse events as migration and spawning cues. Key determinants of the rate and extent of periphyton accrual are closely related to nutrient supply and flow velocities.

Table 7-1 shows that the eight allocation methods only change the frequency of occurrence of FRE_3 events to a small extent. Methods 1, 3, 5 and 7 decrease the frequency to once every 28 days, while Methods 2, 4, 6 and 8 decrease it to once every 29 days.

In favourable conditions, problematic periphyton biomass can accumulate over periods of continuous low flows of five weeks or longer (MfE 1998). River levels and flow velocities over the winter / spring period are consistently higher than those of the summer low flow period. Water temperature and daylight hours during this period are also shorter, limiting the potential for abundant periphyton growth.

Considering these factors in the context of the reduced frequency in biologically significant flow events (Table 7-1), adoption of any of the eight high flow allocation options is considered not to present significant risk of adverse periphyton accrual.

7.2.2 Maintenance of Water Quality

7.2.2.1 Point Source Discharges and Dilution Requirements

As detailed in MWH (2008), point source discharges to the Ngaruroro River are expected to have low containment loads and to be of little concern to water quality during the high-flow period, particularly given the expected high dilution potential and the considerable assimilation capacity of the Ngaruroro River.

Consideration of dilution requirements during the winter high-flow period therefore relates to diffuse, rather than point source discharges.

7.2.2.2 Historical Water Quality over High-Flow Period.

The RRMP (HBRC 2006) specifies that the water quality guidelines are to be achieved as detailed in Table 7-2.

Table 7-2: RRMP Surface Water Quality Guidelines

Issue	Guideline
Temperature	The temperature of the water should be suitable for sustaining the aquatic habitat (i.e. not changed by more than 3℃, nor raised above 25℃)
Dissolved oxygen	The concentration of dissolved oxygen should exceed 80% of saturation concentration
Ammoniacal nitrogen	The concentration of ammoniacal ($N\text{-}NH_4^+$) should not exceed 0.1mg/l
Soluble reactive phosphorus	The concentration of soluble reactive phosphorus should not exceed 0.015 mg/l
Faecal coliforms (cfu/100ml)	50*, 100**, 150***
Suspended solids (mg/l)	10*, 25**, 25***

*Note: * Upstream of Fernhill Bridge*
*** Between Fernhill Bridge and Expressway Bridge;*
**** Downstream of Expressway Bridge.*

The guidelines provided above apply when the river is <u>at or below median flow</u>, with the exception of suspended solids, which applies to all flow conditions.

Historical water quality over the high-flow period (June to November inclusive) has been assessed against the surface water quality guidelines presented in Table 7-2 above at three sample sites, over a range of flow rates (MWH 2008).

The historical water quality results analysed were maximum recorded values, and therefore representative of 'worst case' water quality. Given the limited change in flood frequency by any of the eight allocation methods and that allocation will occur when river flows are greater than mean or median flows, adverse impacts to water quality are not anticipated.

7.2.3 Habitat Requirements

7.2.3.1 IFIM Results in the Context of Naturalised Flow Regime

Instream flow incremental methodology analysis has been applied to the Ngaruroro River on two occasions (Wood 1997 and Wood *et al* 2001). Both applications have focused on habitat requirements for instream biota during summer low flow conditions. In summary these assessments found that adequate aquatic ecosystem habitat requirements were satisfied at flows in the order of 2.4 to 3 m^3/s.

Given that the allocation methods investigated here are concerned with flows above mean and median flow rates (40 and 24 m^3/s respectively), it is expected that usable habitat area (primarily the factors - depth, width and velocity) will be uncompromised by any of the high flow allocation methods. This could be confirmed through application of the Ngaruroro River IFIM data for modelled flow conditions under flow conditions of the high-flow allocation options.

7.2.3.2 Fish Passage

Seventeen fish species of the Ngaruroro River have a seagoing phase to their life history, requiring passage either to or from the sea during the high-flow period to fulfil a phase of their lifecycle. Under the eight allocation options, fish passage within the river itself is expected to be no more constrained (if at all) than under the current flow regime (i.e. through reduced river levels). Table 7-3 presents migration periods for the diadromous fish of the Ngaruroro River in relation to the high-flow period.

Table 7-3: Migration Periods of Diadromous Fishes of the Ngaruroro River

Migration Periods of Diadromous Fishes of the Ngaruroro River															
Common name	**Direction**	**Life stage**	**During high-flow**	J	F	M	A	M	**J**	**J**	**A**	**S**	**O**	**N**	D
Short finned eel	Up	Juvenile	Yes												
	Down	Adult													
Long finned eel	Up	Juvenile	Yes												
	Down	Adult													
Torrent fish	Up	Juvenile	Yes												
	Down	Larva													
Koaro	Up	Juvenile	Yes												
	Down	Larva	Yes												
Inanga	Up	Juvenile	Yes												
	Down	Larva	Yes												
Common bully	Up	Juvenile													
	Down	Larva	Yes												
Giant bully	Up	Juvenile		?	?									?	?
	Down	Larva													
Bluegilled bully	Up	Juvenile		?											
	Down	Larva	Yes												
Redfinned bully	Up	Juvenile													
	Down	Larva	Yes												
Lamprey	Up	Adult	Yes												
	Down	Juvenile	Yes			?									
Common smelt	Up	Adult	Yes												
	Down	Larva	Yes												
Black flounder	Up	Juvenile	Yes												
	Down	Adult													
Brown trout	Up	Adult	Yes												
	Down	Juvenile	Yes												

Note: less intense migration
probable main migration period.
Data compiled from HBRC, NIWA Freshwater Database, and MfE, (1998), Waikato Regional Council (2007).

A large proportion of New Zealand's diadromous fishes migrate from the sea to freshwater in spring (Jowett *et al,* 2005). For all diadromous species, upstream and downstream migrations are equally necessary for maintaining populations (McDowall, 1995).

The Ngaruroro River mouth closure regime is controlled by the dynamic balance of forces between river flow magnitude and coastal wave energy. Historical records of mechanical opening of the river mouth by HBRC provide an indication of which months the river mouth tends to close. Over the years for which data is available, the river mouth has been mechanically opened during four out of the six month June to November high flow period.

Given the limited variation in flood frequency and magnitude imposed by the supported allocation methods, it is expected that any of the methods will not significantly affect the river mouth opening regime. It is however recommended that this aspect be monitored by the Regional Council and that as far as practicable, the river mouth be manually kept open during spring and early summer.

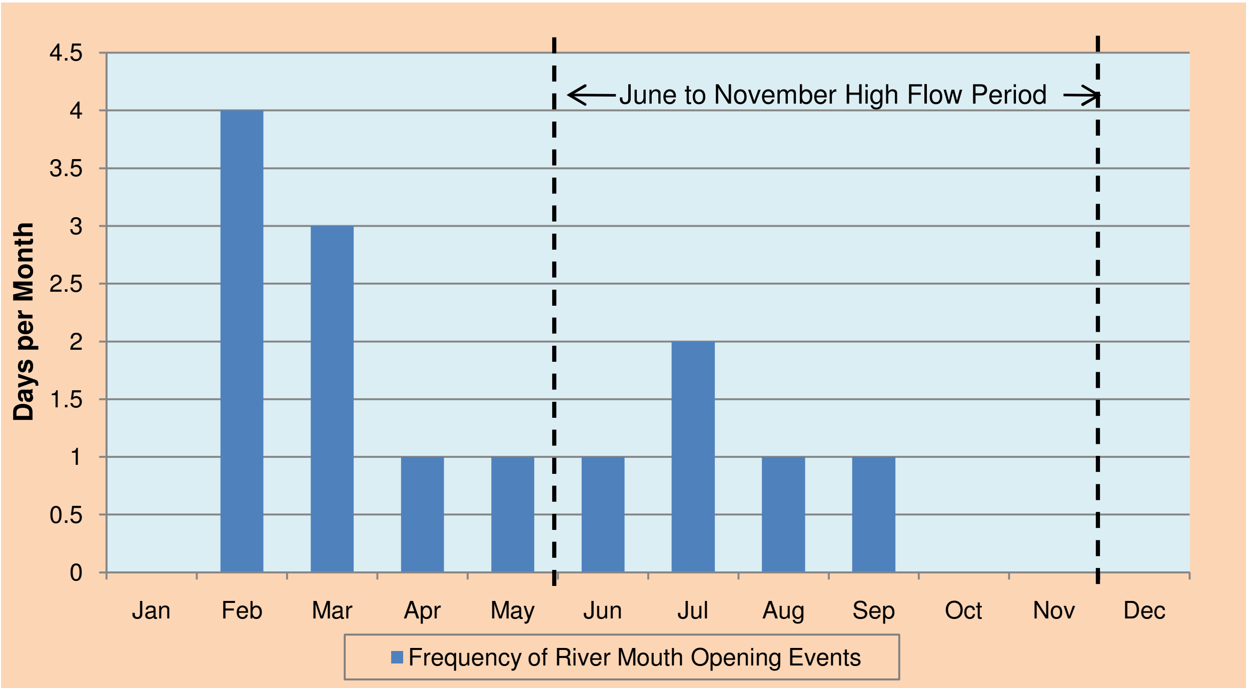

Figure 7-2: Frequency of Ngaruroro River Mouth Opening Events

7.3 Ecological Summary

FRE_3 is an indicator of flood events that cause ecological disturbance. A degree of change of ≤10% reduction from the naturalised FRE_3 value has been used as a selection criterion for the high flow allocation options. Based on this criterion all eight allocation options are supported as being suitable allocation methods while maintaining ecological instream values of the Ngaruroro River.

Assessment of historical water quality data relating to the winter spring period over three monitoring sites shows full compliance with RRMP surface water quality standards for water temperature, and non-compliance of varying degrees for DO, FC, DRP, SS and ammonia (MWH 2008). Considering the limited change in flood frequency (duration and intensity) as determined by the FRE_3 statistic, water quality during the winter – spring period is not expected to be significantly affected.

The IFIM has historically been applied to the Ngaruroro River in relation to summer low flow studies. The IFIM investigation found sufficient weighted usable habitat area to support instream fauna at flows in the order of 2.4 m^3/s. Given the eight allocation options will be operating above mean or median flows, wetted usable area is not expected to be compromised by any reduction in flows under any of the allocation options.

Sixteen diadromous fish species known to be present in the Ngaruroro River move from fresh to salt water during the winter / spring period. These species rely on an open river mouth in order to fulfil their life cycle. While only limited variation in flood frequency is expected under any of the supported allocation methods it is recommended that the natural river mouth opening regime be monitored and augmented as practicable (by mechanical opening) in order to provide for these fish species functional requirements. Hydraulic modelling could also be carried out to assess any effects of variation in flood magnitude on maintaining an open river mouth.

8 Range of Variability Approach (RVA)

A method of assessing the degree of hydrologic alteration attributable to human impacts within a river ecosystem has been developed, referred to as the Range of Variability Approach (RVA). A RVA analysis uses the results from an Indicators of Hydrologic Alteration (IHA) analysis. The RVA and IHA methods are based upon analyses of measured and/or modelled hydrologic data using the software package '*Indicators of Hydrologic Alteration v7*' developed by The Nature Conservancy (TNC). The software is a useful tool for calculating the characteristics of natural and altered flow regimes.

For this study both an IHA analysis and a RVA analysis have been carried out and the results presented in Section 8.1 and Section 8.2 respectively.

For the purposes of the analyses, datasets of the Ngaruroro River flow at Fernhill are constructed combining the naturalised and altered flow data. The IHA software requires one dataset of continuous flow with a defined break where flow alteration begins (e.g. abstraction starts or a dam is built etc). Therefore, datasets have been compiled for each of the high flow allocation methods using daily flows for the naturalised data from 1970 to 1995 and the corresponding altered data to begin in 1996 and end in 2021.

Appending the altered flow data to the naturalised flow data allows a direct RVA analysis and comparison of 'pre' and 'post' impact flows with a defined break at the end of 1995.

RVA and IHA analyses use 32 different parameters (called IHA parameters), organised into five groups, to statistically characterise hydrologic variation within each year. These 32 parameters provide information on some of the most ecologically significant features of the flow regime influencing aquatic ecosystems.

Table 8-1 details the IHA parameters divided into the five major groupings. Sixteen of the hydrologic parameters focus on the magnitude, duration, timing, and frequency of extreme events. Because of the influence of extreme forces in ecosystems; the other 16 parameters measure the central tendency of either the magnitude or rate of change of water conditions (TNC 2007).

The idea behind the use of IHA parameters is that river management decisions have tended to focus on the known or perceived hydrologic requirements of a few target aquatic species, potentially neglecting the needs of other species and ecosystem processes and functions in general.

The RVA process analyses the hydrologic perturbations associated with activities such as abstraction, dam operations, ground water pumping or intensive land use conversion by comparing the hydrologic indicators between "pre-impact" and "post-impact" flows. In this investigation the RVA analysis will look at the effects of high flow allocation abstraction on the naturalised Ngaruroro River flows (pre-impact) and the altered Ngaruroro Rivers flows (post impact).

Table 8-1: Summary of IHA Parameters and their Ecosystem Influences

Parameter Group	Regime Characteristics	Streamflow Parameters Used in the IHA	Examples of Ecosystem Influences
1. Magnitude of Monthly Discharge Conditions	Magnitude Timing	1. Mean discharge for each calendar month	Habitat availability for aquatic organisms Soil moisture availability for plants Availability of water for terrestrial animals Availability of food/cover for fur-bearing mammals Reliability of water supplies for terrestrial animals Access by predators to nesting sites Influences water temperature, oxygen levels, photosynthesis
2. Magnitude and Duration of Annual Extreme Discharge Conditions	Magnitude Duration	1. Annual maxima one-day means 2. Annual minima one-day means 3. Annual minima 3-day means 4. Annual maxima 3-day means 5. Annual minima 7-day means 6. Annual maxima 7-day means 7. Annual minima 30-day means 8. Annual maxima 30-day means 9. Annual minima 90-day means 10. Annual maxima 90-day means 11. Number of zero-flow days 12. 7-day minimum flow divided by mean flow for year	Balance of competitive, ruderal, and stress-tolerant organisms Creation of sites for plant colonization Structuring of aquatic ecosystems by abiotic vs. biotic factors Structuring of river channel morphology and physical habitat Soil moisture stress in plants Dehydration in animals Anaerobic stress in plants Volume of nutrient exchanges between rivers and floodplains Duration of stressful conditions such as low oxygen and concentrated chemicals in aquatic environments Distribution of plant communities in lakes, ponds, floodplains Duration of high flows for waste disposal, aeration of spawning beds in channel sediments
3. Timing of Annual Extreme Discharge Conditions	Timing	1. Julian date of each annual one-day maximum discharge 2. Julian date of each annual one-day minimum discharge	Compatibility with life cycles of organisms Predictability/avoidability of stress for organisms Access to special habitats (reproduction) or to avoid predation Spawning cues for migratory fish Evolution of life history strategies, behavioural mechanisms
4. Frequency and Duration of High/Low Flow Pulses	Magnitude Frequency Duration	1. Number of high pulses each year 2. Number of low pulses each year 3. Mean duration of high pulses within each year 4. Mean duration of low pulses within each year	Frequency and magnitude of soil moisture stress for plants Frequency and duration of anaerobic stress for plants Availability of floodplain habitats for aquatic organisms Nutrient and organic matter exchanges between river and floodplain Soil mineral availability Access for waterbirds to feeding, resting, reproduction sites Influences bedload transport, channel sediment textures, and duration of substrate disturbance (high pulses)
5. Rate/ Frequency of Hydrograph Changes	Frequency Rate of Change	1. Means of all positive differences between consecutive daily values 2. Means of all negative differences between consecutive daily values 3. Number of flow reversals	Drought stress on plants (falling levels) Entrapment of organisms on islands, floodplains (rising levels) Desiccation stress on low-mobility stream edge (varial zone) organisms

8.1 IHA Summary

Analysing the natural and altered flow data for the Ngaruroro River at Fernhill within the IHA software results in a 'scorecard table' that details a variety of statistics for both the naturalised and altered data (resulting from each allocation method) for each hydrologic parameter.

Table 8-2 summarises the IHA scorecard output for the altered river flows due to the high flow allocation scenarios as compared to the naturalised river flow. The results are for non-parametric (percentile) statistics.

The table details median monthly flows for the June to November period (Parameter Group 1), the median of the minimum and maximum flows (Parameter Group 2), and high and low pulse count (Parameter Group 4). The high pulse threshold is set at 71 m^3/s, which is the FRE_3 value (three times the median) of the naturalised flow data.

The very first column gives the values for the naturalised Ngaruroro River at Fernhill flow record (pre-impact).

The first column for each of the high flow allocation methods shows the comparative median value to the naturalised flow record. The second column for the each of the methods shows the 'deviation' from the naturalised flow. The third column of each of the methods is the 'significance count'. The IHA software randomly shuffles all the years of input data and recalculates (fictitious) pre and post-impact medians 1000 times. The significance count is the fraction of trials for which the deviation values of the medians were greater than for the real case. A low significance count (minimum value is 0) means that the difference between the pre and post-impact flows is highly significant. A high significance count (maximum value is 1) means there is little difference.

In terms of median monthly flows, Methods 6 and 8 show the lowest significance counts and therefore have, comparatively, the most highly significant differences from the naturalised (pre-impact) flow.

All of the high flow allocation methods result in an altered flow regime that changes the median maximum flow parameters to some degree. Those that cause the biggest differences are Methods 2, 6 and 8. These and Method 4 show the greatest impact on the high pulse count in terms of significance count – although all eight methods return the same median high pulse count of 6.

Method 1 has the least significant impact on the maximum flow parameters.

Table 8-2: IHA Scorecard Summary

	NATURAL	METHOD 1			METHOD 2			METHOD 3			METHOD 4		
	Median (m^3/s)	Median (m^3/s)	Dev Factor	Sig Count	Median (m^3/s)	Dev Factor	Sig Count	Median (m^3/s)	Dev Factor	Sig Count	Median (m^3/s)	Dev Factor	Sig Count
Parameter Group #1													
June	32.9	33.4	0.02	0.90	33.4	0.02	0.92	33.4	0.02	0.93	33.4	0.02	0.93
July	50.5	49.1	0.03	0.89	46.1	0.09	0.71	49.1	0.03	0.89	47.4	0.06	0.75
August	49.4	45.2	0.08	0.76	43.7	0.12	0.66	45.2	0.08	0.75	44.9	0.09	0.73
September	37.5	37.5	0	1	37.5	0	1	37.5	0	1	37.5	0	1
October	33.2	33.2	0	1	33.2	0	1	33.2	0	1	33.2	0	1
November	20.7	20.7	0	1	20.68	0	1	20.68	0	1	20.7	0	1
Parameter Group #2													
1-day minimum	8.6	8.5	0.012	0.95	8.5	0.012	0.96	8.5	0.012	0.95	8.5	0.012	0.95
3-day minimum	8.9	8.9	0.002	1	8.9	0.002	1	8.9	0.002	1	8.9	0.002	1
7-day minimum	9.6	9.6	0	1	9.6	0	1	9.6	0	1	9.6	0	1
30-day minimum	19.2	19.2	0.002	0.99	19.2	0.003	0.98	19.2	0.002	0.99	19.2	0.002	0.99
90-day minimum	32.7	32.1	0.02	0.80	31.6	0.03	0.63	32.1	0.02	0.80	31.7	0.03	0.64
1-day maximum	409.6	407.6	0.005	0.94	404.6	0.01	0.80	407.6	0.005	0.94	404.6	0.01	0.81
3-day maximum	295.9	293.9	0.01	0.98	290.9	0.02	0.94	293.9	0.01	0.98	290.9	0.02	1
7-day maximum	201.8	199.8	0.01	0.90	196.8	0.02	0.86	199.8	0.01	0.88	196.8	0.02	1
30-day maximum	109.1	107.1	0.02	0.89	104.1	0.05	0.79	107.1	0.02	0.89	104.2	0.04	0.81
90-day maximum	73.1	71.6	0.02	0.68	69.6	0.05	0.56	71.7	0.02	0.72	69.9	0.04	0.59
Number of zero days	0	0			0			0			0		
Base flow index	0.21	0.21	0.01	0.80	0.22	0.03	0.43	0.21	0.01	0.83	0.22	0.03	0.47
Parameter Group #4													
Low pulse count	4.5	4.5	0	1	4.5	0	1	4.5	0	1	5	0	1
Low pulse duration	6.0	6.3	0.042	0.53	6.3	0.042	0.51	6.3	0.042	0.52	6.3	0.042	0.53
High pulse count	6.5	6	0.077	0.72	6	0.077	0.56	6	0.077	0.72	6	0.077	0.56
High pulse duration	3	3	0	0.06	3	0	0.10	3	0.00	0.06	3	0	0.12
Low Pulse Threshold	19.0												
High Pulse Threshold	71.3												

	NATURAL	METHOD 5			METHOD 6			METHOD 7			METHOD 8		
	Median (m^3/s)	Median (m^3/s)	Dev Factor	Sig Count	Median (m^3/s)	Dev Factor	Sig Count	Median (m^3/s)	Dev Factor	Sig Count	Median (m^3/s)	Dev Factor	Sig Count
Parameter Group #1													
June	32.9	31.4	0.05	0.73	28.7	0.13	0.53	31.4	0.05	0.72	30.2	0.08	0.59
July	50.5	49.1	0.03	0.88	46.1	0.09	0.70	49.1	0.03	0.90	46.1	0.09	0.68
August	49.4	45.2	0.08	0.77	42.2	0.14	0.57	45.2	0.08	0.80	42.2	0.14	0.56
September	37.5	35.5	0.05	0.55	32.5	0.13	0.37	35.5	0.05	0.54	33.0	0.12	0.34
October	33.2	31.2	0.06	0.90	28.7	0.14	0.55	31.2	0.06	0.90	30.0	0.10	0.66
November	20.7	20.7	0	1	20.68	0	1	20.7	0	1	20.7	0	1
Parameter Group #2													
1-day minimum	8.6	8.5	0.012	0.95	8.5	0.012	0.93	8.5	0	1	8.5	0	1
3-day minimum	8.9	8.9	0.002	1	8.9	0.002	1.00	8.9	0	1	8.9	0	1
7-day minimum	9.6	9.6	0	1	9.6	0	1	9.6	0	1	9.6	0	1
30-day minimum	19.2	18.9	0.02	0.88	18.8	0.02	0.86	19.0	0.01	0.91	18.9	0.02	0.84
90-day minimum	32.7	31.3	0.04	0.48	30.2	0.07	0.39	31.4	0.04	0.54	30.5	0.07	0.40
1-day maximum	409.6	407.6	0.005	0.93	404.6	0.01	0.81	407.6	0.005	0.93	404.6	0.01	0.79
3-day maximum	295.9	293.9	0.01	1	290.9	0.02	0.95	293.9	0.01	1	290.9	0.02	1
7-day maximum	201.8	199.8	0.01	0.88	196.8	0.02	0.87	199.8	0.01	0.91	196.8	0.02	0.86
30-day maximum	109.1	107.1	0.02	0.87	104.1	0.05	0.79	107.1	0.02	0.89	104.1	0.05	0.80
90-day maximum	73.1	71.1	0.03	0.64	68.4	0.06	0.56	71.2	0.03	0.63	68.5	0.06	0.57
Number of zero days	0	0			0			0.00			0.00		
Base flow index	0.21	0.21	0.02	0.71	0.22	0.06	0.28	0.21	0.02	0.70	0.22	0.05	0.33
Parameter Group #4													
Low pulse count	4.5	5	0	1	4.5	0	1	4.5	0	1	4.5	0	1
Low pulse duration	6.0	6.3	0.042	0.51	6.3	0.042	0.50	6.3	0.042	0.52	6.3	0.042	0.54
High pulse count	6.5	6	0.077	0.73	6	0.077	0.58	6	0.077	0.74	6	0.077	0.55
High pulse duration	3	3	0	0.06	3	0	0.10	3	0	0.05	3	0.00	0.09
Low Pulse Threshold	19.0												
High Pulse Threshold	71.3												

8.2 RVA Summary

The RVA analyses of the eight high flow allocation methods are summarised.

The RVA analyses output 'Hydrologic Alteration Factors' for three RVA categories which quantify the degree of alteration of the IHA flow parameters.

The RVA process divides the full range of pre-impact data for each of the 32 IHA parameters into three categories based on percentile values. The lowest category contains all values less than or equal to the 33^{rd} percentile; the middle category contains all values filling the range between the 34^{th} and 67^{th} percentile; and the highest category contains all the values greater than the 67^{th} percentile.

The IHA software computes the expected frequency with which the post impact values of the IHA parameters should fall into each category (i.e. 33% for each of the three categories in this case). The frequency with which the post-impact values actually fall within the categories is computed. A Hydrologic Alteration Factor based on the observed and expected frequencies is calculated.

A positive Hydrologic Alteration Factor means that the frequency of values in the category has increased from the pre-impact to post-impact data. A negative value means it has decreased.

Figure 8-1 and Figure 8-2 are examples of the graphical RVA output. Figure 8-1 compares August Monthly Flows between the naturalised and Method 4 flow data. Figure 8-2 shows the difference in Annual 7-Day Maximum Flow between the naturalised and Method 6 flow data.

The RVA results for the Hydrologic Alteration Factors are summarised in Table 8-3 for the eight high flow allocation methods (Section 5).

In both figures the naturalised flow record (pre-impact) is shown as the years 1970 to 2007 (green line) and the altered (post-impact) flow record is shown as the years the 2007 to 2045 period (red line). Both datasets are actually for the 1970 to 2007 period but for the RVA analyses they need to run consecutively in a single dataset with a defined break at the end of 2007 so that changes in the flow regime can be analysed.

Figure 8-1 shows the effect that the high flow allocation Method 4 would have on monthly flows for August. The number of occurrences above the RVA high boundary noticeably decreases for the altered river flow (red line) due to the allocation scenario.

The top left corner of the figure details the Hydrologic Alteration factors for the three categories (high, middle and low). The high Hydrologic Alteration category has a value of -0.25 meaning there has been a decrease in this category due to the altered flow regime.

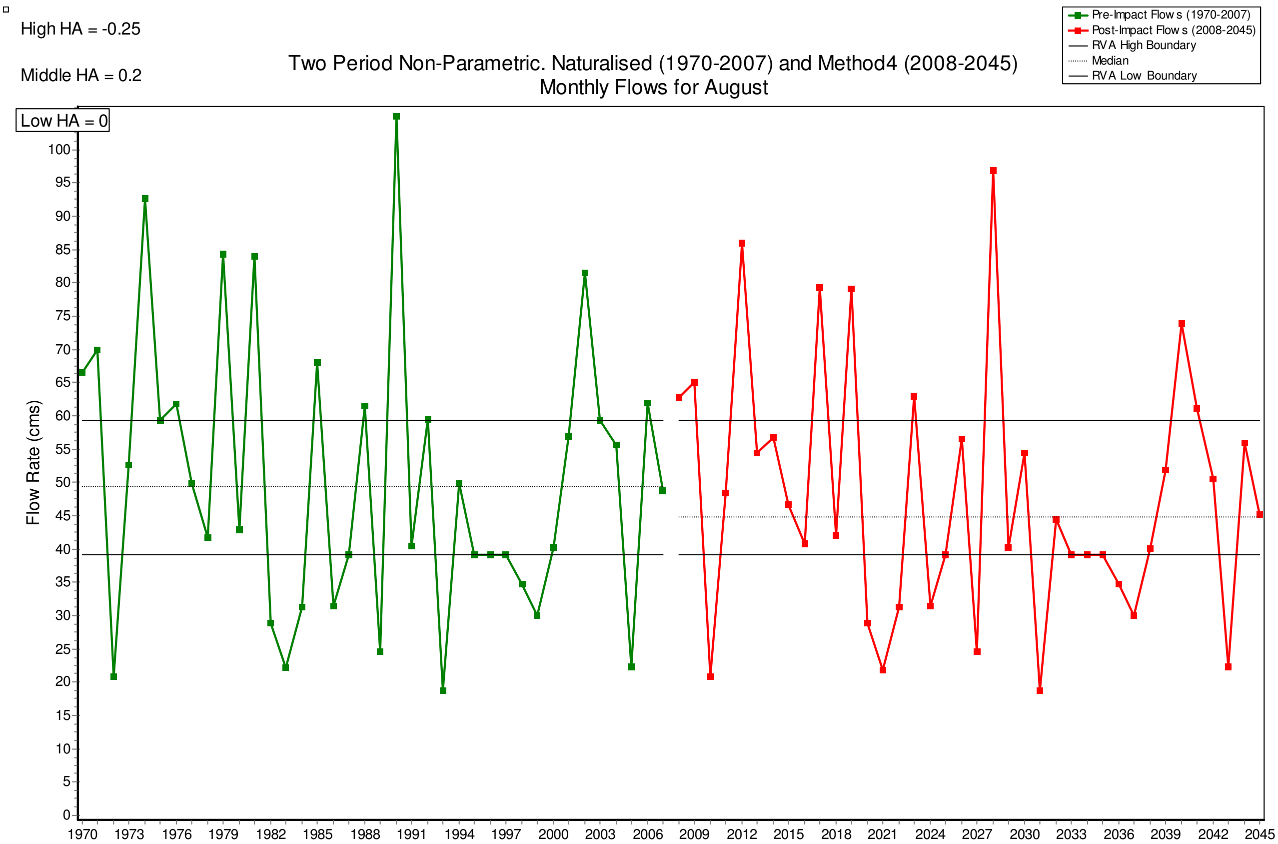

Figure 8-1: RVA Analysis of August Monthly Flow – Naturalised (green) versus Method 4 (red)

There has been an increase (0.2) in the middle category, due to values dropping out of the high category and into the middle range. This is clearly displayed in Figure 8-1 with more August monthly flows filling the middle RVA category for the altered flow. The dashed line shows how the median August flow has changed between the two flow series.

Figure 8-2 details the 7-Day maximum flow for the naturalised (pre-impact) and Method 6 altered (post-impact) flows.

The number of high flow occurrences has not changed in the high Hydrologic Alteration category due to the high flow allocation scenario – although it is evident that the magnitude of each event has decreased slightly., while the frequency of occurrences in the low category has increased.

There has been a decrease in the middle Hydrologic Alteration category and an increase in the low Hydrologic Alteration category as 7-Day maximum flow events move from the middle to low categories.

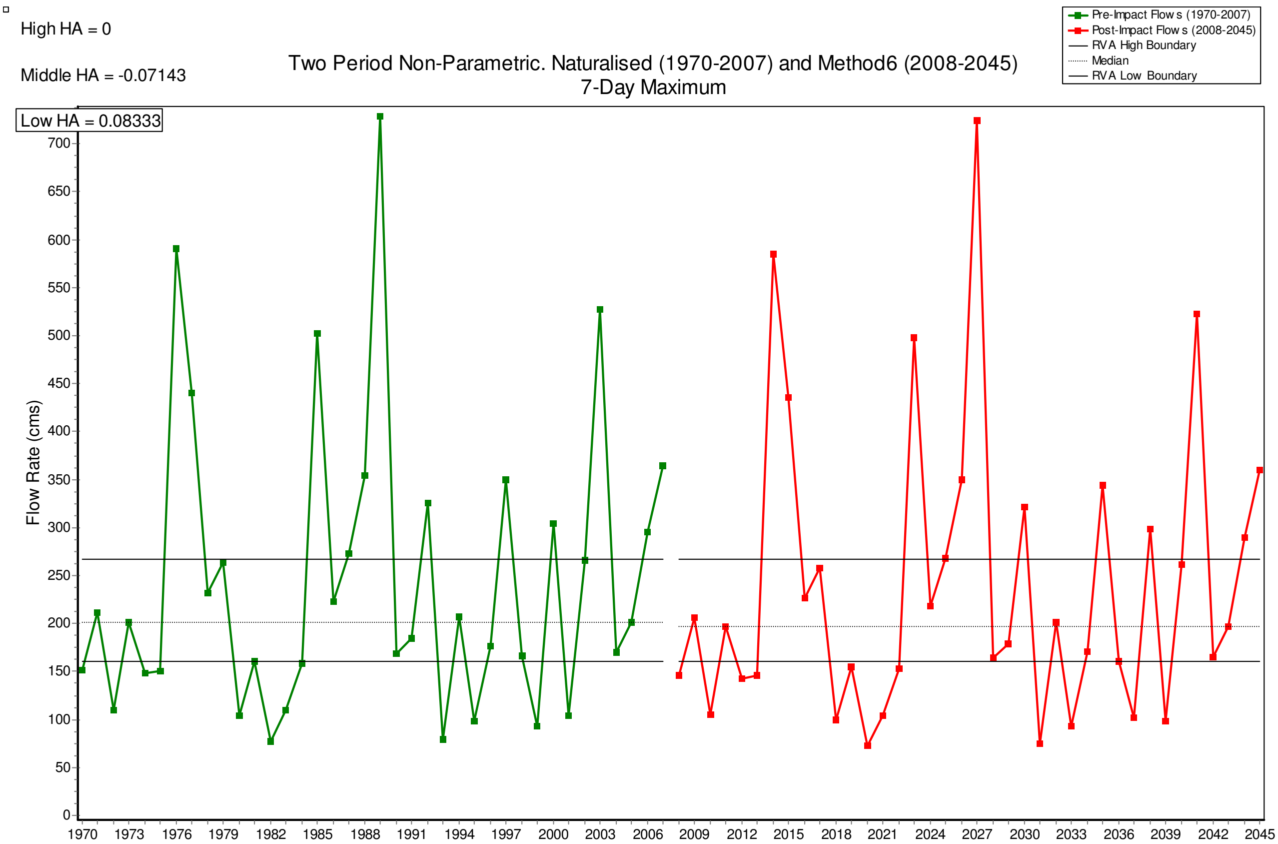

Figure 8-2: RVA Analysis of 7-Day Maximum Flow – Naturalised (green) versus Method 6 (red)

Table 8-3 summarises the RVA analysis results for the eight high flow allocation methods.

All Methods show decreases in the high Hydrologic Alteration category for most parameters. Conversely, most methods show an increase in the low Hydrologic Alteration category.

Overall, Methods 1, 2, 3 and 4 show the smallest changes to the RVA categories. This is due to the high flow allocation not being able to be accessed until the mean flow is exceeded. Whereas the other four methods use the median flow as the threshold and water can be abstracted more often.

Although some methods have larger changes to the RVA categories than others, all eight methods are really only producing minor effects on the indicators of hydrological alteration and the overall flow regimes.

Table 8-3: RVA Analysis Summary

	Method 1			Method 2			Method 3			Method 4		
	High	Middle	Low	High	Middle	Low	High	Middle	Low	High	Middle	Low
Parameter Group #1												
June	0	0.07	-0.08	0	0.07	-0.08	0	0.07	-0.08	0	0.07	-0.08
July	-0.17	0.14	0	-0.33	0.29	0	-0.17	0.14	0	-0.33	0.29	0
August	-0.08	0.07	0	-0.25	0.20	0	-0.08	0.07	0	-0.25	0.20	0
September	-0.08	0	0.08	-0.17	0.07	0.08	-0.08	0	0.08	-0.17	0.07	0.08
October	-0.17	0.07	0.08	-0.33	0.21	0.08	-0.17	0.07	0.08	-0.25	0.14	0.08
November	-0.17	0.14	0	-0.17	0.14	0	-0.17	0.14	0	-0.17	0.14	0
Parameter Group #2												
1-day minimum	0	0	0	0	0	0	0	0	0	0	0	0
3-day minimum	0	0	0	0	0	0	0	0	0	0	0	0
7-day minimum	0	0	0	0	0	0	0	0	0	0	0	0
30-day minimum	0.08	-0.14	0.08	0.08	-0.14	0.08	0.08	-0.14	0.08	0.08	-0.14	0.08
90-day minimum	-0.17	0.07	0.08	-0.17	-0.07	0.25	-0.17	0.07	0.08	-0.17	0	0.17
1-day maximum	0	-0.07	0.08	-0.08	0	0.08	0	-0.07	0.08	-0.08	0	0.08
3-day maximum	-0.08	0.07	0	-0.08	0.07	0	-0.08	0.07	0	-0.08	0.07	0
7-day maximum	0	-0.07	0.08	0	-0.07	0.08	0	-0.07	0.08	0.00	-0.07	0.08
30-day maximum	-0.08	0	0.08	-0.17	0	0.17	-0.08	0	0.08	-0.17	0	0.17
90-day maximum	-0.08	0	0.08	-0.08	0	0.08	-0.08	0	0.08	-0.08	0	0.08
Parameter Group #4												
High pulse count	-0.25	0.04	0.17	-0.25	0	0.33	-0.25	0.04	0.17	-0.25	0	0.33
High pulse duration	0	-0.18	0.33	-0.08	-0.29	0.67	0	-0.18	0.33	-0.08	-0.29	0.67

	Method 5			Method 6			Method 7			Method 8		
	High	Middle	Low	High	Middle	Low	High	Middle	Low	High	Middle	Low
Parameter Group #1												
June	0	-0.07	0.08	-0.17	0.07	0.08	0	0.07	-0.08	-0.17	0.21	-0.08
July	-0.17	0	0.17	-0.33	0.07	0.25	-0.17	0	0.17	-0.33	0.07	0.25
August	-0.08	-0.33	0.55	-0.25	-0.27	0.64	-0.08	-0.33	0.55	-0.25	-0.27	0.64
September	-0.08	-0.07	0.17	-0.17	-0.07	0.25	-0.08	-0.07	0.17	-0.17	-0.07	0.25
October	-0.17	-0.14	0.33	-0.33	0	0.33	-0.17	-0.07	0.25	-0.33	0.07	0.25
November	-0.17	0.14	0	-0.17	0.14	0	-0.17	0.14	0	-0.17	0.14	0
Parameter Group #2												
1-day minimum	0	0	0	0	0	0	0	0	0	0	0	0
3-day minimum	0	0	0	0	0	0	0	0	0	0	0	0
7-day minimum	0	0	0	0	0	0	0	0	0	0	0	0
30-day minimum	0	-0.14	0.17	0	-0.14	0.17	0	-0.14	0.17	0	-0.14	0.17
90-day minimum	-0.17	-0.07	0.25	-0.17	-0.07	0.25	-0.17	-0.07	0.25	-0.17	-0.07	0.25
1-day maximum	0.00	-0.07	0.08	-0.08	0	0.08	0	-0.07	0.08	-0.08	0	0.08
3-day maximum	-0.08	0.07	0	-0.08	0.07	0	-0.08	0.07	0	-0.08	0.07	0
7-day maximum	0	-0.07	0.08	0	-0.07	0.08	0	-0.07	0.08	0	-0.07	0.08
30-day maximum	-0.08	0	0.08	-0.17	0	0.17	-0.08	0	0.08	-0.17	0	0.17
90-day maximum	-0.08	0	0.08	-0.08	-0.14	0.25	-0.08	0	0.08	-0.08	-0.07	0.17
Parameter Group #4												
High pulse count	-0.25	0.04	0.17	-0.25	0	0.33	-0.25	0.04	0.17	-0.25	0	0.33
High pulse duration	0	-0.18	0.33	-0.08	-0.29	0.67	0	-0.18	0.33	-0.08	-0.29	0.67

9 Summary/Discussion

Increasing demand on the water resource of the Ngaruroro River has led to an investigation of the potential of a high flow allocation to allow water harvesting and storage of water during the winter/spring (June to November) months for subsequent use when water resources are limited in availability during the summer and autumn period.

Eight high flow allocation methods have been modelled and investigated to determine a suitable method of allocating flow during times of higher river flow (June to November) that has minimal impact on the river ecology and hydrology. Table 9-1 details the eight methods investigated.

Table 9-1: High Flow Allocation Scenarios

Scenario	Description
Method 1	If river flow > MEAN, then 50% of flow above the MEAN allocated **- up to a maximum of 2 m^3/s**
Method 2	If river flow > MEAN, then 50% of flow above the MEAN allocated **- up to a maximum of 5 m^3/s**
Method 3	If river flow > MEAN, then 33% of flow above the MEAN allocated **- up to a maximum of 2 m^3/s**
Method 4	If river flow > MEAN, then 33% of flow above the MEAN allocated **- up to a maximum of 5 m^3/s**
Method 5	If river flow > MEDIAN, then 50% of flow above the MEDIAN allocated **- up to a maximum of 2 m^3/s**
Method 6	If river flow > MEDIAN, then 50% of flow above the MEDIAN allocated **- up to a maximum of 5 m^3/s**
Method 7	If river flow > MEDIAN, then 33% of flow above the MEDIAN allocated **- up to a maximum of 2 m^3/s**
Method 8	If river flow > MEDIAN, then 33% of flow above the MEDIAN allocated **- up to a maximum of 5 m^3/s**

Note - Median and mean are from entire period of flow record

Hydrological analyses showed small variations between the naturalised and altered Ngaruroro River flow for each high flow allocation method.

Results of the ecological analyses of the methods recommend that in order to maintain instream ecological values, the mean FRE_3 value for the Ngaruroro River should not be changed by more than 10% of its naturalised flow value. All eight high flow allocation methods investigated alter the FRE_3 value by less than 10%.

Additional ecological analyses including water quality and temperature assessments, instream habitat, and fish passage concluded that there would be no significant effects from any of the high flow allocation methods.

A Range of Variability Approach (RVA) analysis investigated the degree of hydrologic alteration between the naturalised flow (pre-impact) and altered flow (post-impact) for 32 hydrological parameters that statistically characterise ecologically significant features of the flow regime.

The RVA results showed that the four high flow allocation methods based on using the mean flow as the allocation threshold incurred the least hydrologic alteration on the Ngaruroro River flow.

Given the very similar results from the analyses for the eight methods and the only very minor effect they each have on the flow regime and instream ecology of the Ngaruroro River for the months of June to November, it comes down to a preference of what quantity of water should be made available for allocation.

If the desire is to promote and encourage water harvesting for storage then Methods 2, 4, 6 and 8 would be preferable as they offer the greatest allocable volumes.

The allocation scenarios investigated in this study have applied a flow share arrangement, for example 50/50 - where 50% of the flow above a threshold is allocated up to a maximum allocation. This means that for every litre of water allocated a litre must stay in the river above the threshold.

Consideration will need to be given to how this will be managed. Otago Regional Council found it a difficult proposition and instead nominated allocation blocks over and above certain threshold flows. An example situation for the Ngaruroro River might be three allocations blocks:

- A block – this is the core allocation as defined by the minimum flow and the Q_{95}
- B block – the minimum flow for this would be the median/mean flow and an upper limit may be, for example, 3 m^3/s above this, i.e. 3 m^3/s available for allocation
- C block – the minimum flow here could be the FRE_3 value and an allocation limit could be, for example, 2 m^3/s.

This effectively gives three allocation blocks with 'gaps' in between where flow is maintained.

Allocation systems such as this are used in the Otago region. HBRC would need to ascertain whether the Ngaruroro River would require a similar system or if a straight flow sharing arrangement would work best.

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Appendix A: High Flow Allocation Scenarios – Average Weekly Abstraction (m^3/week)

Method 1 if river flow > MEAN, then 50% of flow above the MEAN allocated up to a maximum of 2 m^3/s

Average Weekly Abstraction Volume (m^3/week)

	Jun	Jul	Aug	Sep	Oct	Nov	Mean
1970	645322	763862	922320	820714	697334	322358	695318
1971	405216	965261	1167869	1135210	1053562	955584	947117
1972	602986	897523	312077	94954	7862	30845	324374
1973	927158	504403	819504	636854	319939	161482	561557
1974	209261	1209600	1200528	?	?	?	873130
1975	973728	866678	965866	538272	699754	59875	684029
1976	241920	999734	1136419	1209600	673142	522547	797227
1977	1127347	1209600	1186013	1209600	758419	0	915163
1978	524362	1141862	543715	339898	177206	80438	467914
1979	349574	653184	1022112	1064448	811037	52013	658728
1980	685843	1067472	632621	325987	0	0	451987
1981	1063238	1209600	1209600	1063843	861840	602986	1001851
1982	514080	317520	319939	0	0	0	191923
1983	436061	552787	78019	0	874541	153014	349070
1984	0	108864	469930	771725	269741	0	270043
1985	1208995	693706	1202947	385258	0	0	581818
1986	0	243734	507427	608429	258854	0	269741
1987	0	741485	543110	0	56851	559440	316814
1988	40522	585446	1209600	784426	60480	40522	453499
1989	956189	252806	351389	1115251	1054166	304214	672336
1990	29030	92534	1209600	460858	231034	40522	343930
1991	0	3024	574560	0	0	524362	183658
1992	510451	698544	942883	425174	926554	887242	731808
1993	288490	0	78019	67133	0	40522	79027
1994	404611	393120	700358	246154	616896	504403	477590
1995	393120	1029974	540691	241920	78019	80438	394027
1996	322358	1209600	425779	635645	0	0	432230
1997	700358	880589	552787	769306	879984	0	630504
1998	0	897523	357437	120960	234058	40522	275083
1999	552182	341107	238291	201398	0	362880	282643
2000	322358	1130976	492307	475373	500774	120960	507125
2001	105235	465696	663466	514080	195350	116122	343325
2002	463882	1209600	1209600	471744	278208	0	605506
2003	209261	136685	742090	1209600	786845	80438	527486
2004	650765	944093	1115251	51408	580608	0	557021
2005	967680	870307	58061	80438	739066	191117	484445
2006	955584	1209600	1098922	38102	13306	179021	582422
2007	249178	1209600	730598	175997	156038	0	420235

Minimum	0	0	58061	0	0	0	9677
Mean	474768	729389	724550	494122	401587	189302	502286
Maximum	1208995	1209600	1209600	1209600	1054166	955584	1141258

Method 2 If river flow > MEAN, then 50% of flow above the MEAN allocated up to a maximum of 5 m^3/s

Average Weekly Abstraction Volume (m^3/week)

	Jun	Jul	Aug	Sep	Oct	Nov	Mean
1970	1590019	1518653	2245622	1774483	1454544	796522	1563307
1971	949536	2111962	2829254	2828650	2592778	2291587	2267294
1972	1289434	2168813	734832	215914	7862	30845	741283
1973	2283725	974333	1906330	1483574	708826	403402	1293365
1974	394330	2965939	2956262	?	?	?	2105510
1975	2349648	1978301	2151878	1278547	1502323	120355	1563509
1976	534038	2265581	2664749	2938723	1405555	1080173	1814803
1977	2473027	2939933	2390774	3024000	1774483	0	2100370
1978	1310602	2797805	1032394	767491	332035	201398	1073621
1979	712454	1433981	2443997	2529878	1894838	112493	1521274
1980	1452125	2589149	1330560	616896	0	0	998122
1981	2571005	3024000	3024000	2322432	1782950	1168474	2315477
1982	1151539	708221	703382	0	0	0	427190
1983	1025741	1267056	92534	0	2072045	316915	795715
1984	0	145757	984614	1824077	520128	0	579096
1985	2851632	1607558	2896387	897523	0	0	1375517
1986	0	554602	1204157	1496880	532224	0	631310
1987	0	1807747	1208390	0	56851	1233792	717797
1988	60480	1463011	2978640	1870042	119146	101002	1098720
1989	2232317	426384	878170	2717366	2554070	723341	1588608
1990	29030	209261	3024000	1042070	405216	85882	799243
1991	0	3024	1239235	0	0	1249517	415296
1992	1036022	1575504	2082931	925949	2199658	2090794	1651810
1993	637459	0	179021	127613	0	101002	174182
1994	888451	948326	1611792	532829	1155773	1098317	1039248
1995	782611	2417990	1253146	575770	166320	167530	893894
1996	761443	3010694	902966	1539216	0	0	1035720
1997	1562198	2097446	1309392	1674086	2040595	0	1447286
1998	0	2187562	798336	284256	585446	101002	659434
1999	1300320	741485	460253	449366	0	760838	618710
2000	744509	2769984	928973	959818	1138838	243130	1130875
2001	172368	1076544	1626307	1135210	443923	180835	772531
2002	1067472	3024000	2999808	835834	602986	0	1421683
2003	359251	312077	1807142	3024000	1909354	201398	1268870
2004	1521072	2248042	2537136	88301	1203552	0	1266350
2005	2345414	2004912	73181	200189	1700093	433037	1126138
2006	2180909	3024000	2407709	38102	13306	360461	1337414
2007	588470	3024000	1620864	401587	359856	0	999130
Minimum	0	0	73181	0	0	0	12197
Mean	1084406	1721866	1671667	1146701	898128	423360	1157688
Maximum	2851632	3024000	3024000	3024000	2592778	2291587	2801333

Method 3 If river flow > MEAN, then 33% of flow above the MEAN allocated up to a maximum of 2 m^3/s

Average Weekly Abstraction Volume (m^3/week)

	Jun	Jul	Aug	Sep	Oct	Nov	Mean
1970	645322	715478	913853	768096	647136	322358	668707
1971	390701	927763	1155773	1133395	1051747	945907	934214
1972	570931	890870	307238	90115	4838	20563	314093
1973	927158	472954	806198	612058	304214	161482	547344
1974	181440	1196294	1190246	?	?	?	855994
1975	958003	840672	921715	533434	681005	53222	664675
1976	241920	960422	1113437	1205366	634435	482026	772934
1977	1071706	1209600	1103155	1209600	742090	0	889358
1978	524362	1136419	485654	322963	159667	80438	451584
1979	324778	618106	1006992	1052957	787450	48384	639778
1980	644112	1059005	592704	298771	0	0	432432
1981	1045094	1209600	1209600	1013040	807408	555811	973426
1982	489888	302400	304214	0	0	0	182750
1983	425174	538272	61085	0	859421	142128	337680
1984	0	89510	444528	756000	243734	0	255629
1985	1187827	670118	1192061	377395	0	0	571234
1986	0	240710	507427	607219	238291	0	265608
1987	0	736646	517709	0	37498	533434	304214
1988	39917	585446	1209600	774144	53222	40522	450475
1989	941069	224986	351389	1106179	1040256	296957	660139
1990	19354	87696	1209600	442714	210470	40522	335059
1991	0	1814	538877	0	0	517709	176400
1992	474163	671933	909014	404006	903571	877565	706709
1993	272160	0	78019	58061	0	40522	74794
1994	376790	392515	681610	244339	552787	469930	452995
1995	364694	1010621	529200	241920	78019	80438	384149
1996	319334	1209600	409450	625363	0	0	427291
1997	667699	866074	547949	725760	860026	0	611251
1998	0	894499	342317	120960	234058	40522	272059
1999	542506	326592	221357	195350	0	344736	271757
2000	309053	1118275	440294	449971	488074	108259	485654
2001	87696	452995	663466	503798	191722	104026	333950
2002	453600	1209600	1209600	417312	263088	0	592200
2003	180835	130032	736646	1209600	778378	80438	519322
2004	648950	928368	1092874	47779	542506	0	543413
2005	960422	849139	48384	80438	716083	180835	472550
2006	925344	1209600	1059005	24797	9072	159062	564480
2007	246758	1209600	694915	171158	156038	0	413078
Minimum	0	0	48384	0	0	0	8064
Mean	459648	715478	705197	481421	385862	182045	488275
Maximum	1187827	1209600	1209600	1209600	1051747	945907	1135714

Method 4 If river flow > MEAN, then 33% of flow above the MEAN allocated up to a maximum of 5 m^3/s

Average Weekly Abstraction Volume (m^3/week)

	Jun	Jul	Aug	Sep	Oct	Nov	Mean
1970	1529539	1161821	2178490	1631146	1276128	721526	1416442
1971	935021	1795651	2752445	2807482	2573424	2170022	2172341
1972	1163635	2113776	648346	211075	4838	20563	693706
1973	2208730	805594	1772064	1458778	645926	403402	1215749
1974	336874	2952634	2945981	?	?	?	2078496
1975	2280096	1823472	2014589	1204762	1278547	113702	1452528
1976	479606	2165789	2462746	2816554	1210205	938045	1678824
1977	2301869	2752445	2017008	3024000	1660176	0	1959250
1978	1307578	2702851	809222	728179	218938	201398	994694
1979	637459	1252541	2368397	2378678	1835568	76810	1424909
1980	1270685	2471213	1138838	488678	0	0	894902
1981	2519597	2991946	3024000	2030314	1543450	975542	2180808
1982	1043885	607219	632016	0	0	0	380520
1983	953165	1190246	61085	0	1860365	260669	720922
1984	0	96163	902362	1758154	442714	0	533232
1985	2640557	1542845	2771798	833414	0	0	1298102
1986	0	472349	1139443	1433981	483840	0	588269
1987	0	1790208	1016669	0	37498	1075939	653386
1988	39917	1463011	2860704	1793837	97373	101002	1059307
1989	2085350	285466	878170	2668378	2448230	682819	1508069
1990	19354	204422	3024000	953165	327802	56851	764266
1991	0	1814	1114042	0	0	1150330	377698
1992	830995	1455754	1923264	820109	2148250	2006122	1530749
1993	592099	0	145152	118541	0	84067	156643
1994	801360	890870	1528330	488678	981590	999130	948326
1995	672538	2246832	1099526	551578	142733	110678	803981
1996	726365	2887315	774749	1495670	0	0	980683
1997	1433981	2013984	1208390	1550102	1826496	0	1338826
1998	0	2124662	731203	255830	569117	101002	630302
1999	1195085	627178	374976	391306	0	707616	549360
2000	685238	2756678	742090	812851	1036627	176602	1035014
2001	148176	986429	1603930	919901	416707	119750	699149
2002	1013040	3024000	2879453	635645	546739	0	1349813
2003	305424	286070	1762387	3024000	1856736	168134	1233792
2004	1420070	2159136	2253485	58061	1022112	0	1152144
2005	2199658	1863994	48384	166320	1582157	409450	1044994
2006	2062973	3024000	2196634	24797	9072	335059	1275422
2007	537667	2982269	1473293	334454	336874	0	944093
Minimum	0	0	48384	0	0	0	8064
Mean	1010016	1631146	1559779	1077754	821923	382838	1080576
Maximum	2640557	3024000	3024000	3024000	2573424	2170022	2742667

Method 5 If river flow > MEDIAN, then 50% of flow above the MEDIAN allocated up to a maximum of 2 m^3/s

Average Weekly Abstraction Volume (m^3/week)

	Jun	Jul	Aug	Sep	Oct	Nov	Mean
1970	1187222	1186013	1026346	1193270	1209600	540086	1057090
1971	524362	1131581	1209600	1209600	1109203	1209600	1065658
1972	736042	1185408	432432	312682	117331	40522	470736
1973	1008202	796522	1202947	1109203	647741	244339	834826
1974	545530	1209600	1209600	?	?	?	988243
1975	1209600	1209600	1156982	857606	1186618	498355	1019794
1976	497146	1209600	1209600	1209600	1209600	1181779	1086221
1977	1209600	1209600	1209600	1209600	1209600	354413	1067069
1978	655603	1209600	1209600	789869	596333	254016	785837
1979	959818	1170288	1209600	1209600	1153958	654394	1059610
1980	1057795	1209600	1202947	1175126	160272	130637	822730
1981	1209600	1209600	1209600	1209600	1209600	1205366	1208894
1982	1034813	1111018	703987	84672	156038	49594	523354
1983	826762	980986	306029	344736	1053562	587261	683222
1984	45360	682214	984614	1209600	811037	97978	638467
1985	1209600	1209600	1209600	978566	0	80438	781301
1986	105840	726970	985219	1080778	1061424	0	660038
1987	42336	887846	899338	642298	423360	811037	617702
1988	122774	705197	1209600	1208390	812246	40522	683122
1989	1209600	1181779	549763	1209600	1209600	738461	1016467
1990	453600	644112	1209600	837043	1172102	477792	799042
1991	393725	588470	1138234	283651	425779	727574	592906
1992	1002758	1014250	1209600	1088035	1209600	1150934	1112530
1993	864864	244944	143338	904176	39312	80438	379512
1994	646531	1081382	935021	374371	1137629	998525	862243
1995	1209600	1209600	1071706	781402	668909	321754	877162
1996	327802	1209600	1209600	956794	168739	0	645422
1997	1098922	1209600	1097712	1209600	1209600	141523	994493
1998	15725	1101341	1120694	276394	414893	44150	495533
1999	1004573	827971	910829	480211	0	531014	625766
2000	685238	1189037	1209600	1020902	788054	434246	887846
2001	374371	750557	832810	814061	712454	769910	709027
2002	732413	1209600	1209600	1209600	717898	52618	855288
2003	713664	422755	937440	1209600	1209600	359856	808819
2004	983405	1209600	1209600	1038442	1158192	157248	959414
2005	1209600	1209600	501984	120960	1045094	495936	763862
2006	1209600	1209600	1209600	682819	88906	534643	822528
2007	573955	1209600	1129766	511661	479002	0	650664
Minimum	15725	244944	143338	84672	0	0	81446
Mean	760234	1025136	1016669	866074	756000	432432	809424
Maximum	1209600	1209600	1209600	1209600	1209600	1209600	1209600

Method 6 If river flow > MEDIAN, then 50% of flow above the MEDIAN allocated up to a maximum of 5 m^3/s

Average Weekly Abstraction Volume (m^3/week)

	Jun	Jul	Aug	Sep	Oct	Nov	Mean
1970	2684707	2870381	2542579	2847398	2860099	1189037	2499034
1971	1294272	2820182	3024000	3020976	2747606	2989526	2649427
1972	1778717	2792966	1006992	530410	240106	101002	1075032
1973	2474237	1911168	2698618	2506896	1321488	535853	1908043
1974	1276128	3024000	3024000	?	?	?	2441376
1975	2963520	2874010	2785709	1907539	2777242	854582	2360434
1976	1011226	2991946	3024000	3024000	2785104	2708294	2590762
1977	3024000	3024000	3024000	3024000	2854051	503194	2575541
1978	1535587	3024000	2906064	1684973	1245283	552182	1824682
1979	2136154	2633904	3017347	3022790	2687126	1166054	2443896
1980	2542579	3024000	2823206	2678659	192326	192931	1908950
1981	3024000	3024000	3024000	3024000	2967754	2745792	2968258
1982	2407104	2233526	1504138	84672	199584	58061	1081181
1983	1831939	2193610	594518	535853	2621203	1316650	1515629
1984	97978	1328141	2068416	2872800	1742429	168739	1379750
1985	3024000	2977430	3024000	2151878	0	134870	1885363
1986	134266	1538006	2017008	2414966	2498429	0	1433779
1987	42336	2127082	2010355	972518	821318	1957133	1321790
1988	292723	1642032	3024000	2859494	1357776	101002	1546171
1989	3024000	2316989	1208390	3024000	3024000	1414022	2335234
1990	745718	1026950	3024000	1871251	2448230	680400	1632758
1991	708221	999734	2590963	364694	534643	1717632	1152648
1992	2269210	2481494	2953238	2517782	2900016	2720390	2640355
1993	1919030	309658	319334	1609978	65923	201398	737554
1994	1418861	2445811	2190586	918691	2592173	2293402	1976587
1995	2822602	3024000	2391984	1453334	1120090	580608	1898770
1996	811642	3024000	2673216	2165184	230429	0	1484078
1997	2586730	2901226	2294006	3002832	2921184	200189	2317694
1998	15725	2697408	2295821	538877	936230	104630	1098115
1999	2238365	1723075	1756944	1057795	0	1191456	1327939
2000	1454544	2886710	2802643	2407709	1862179	930182	2057328
2001	743904	1775693	1974067	1909958	1481155	1632355	1586189
2002	1776902	3024000	3024000	3016742	1573085	79834	2082427
2003	1585181	819504	2215987	3024000	2918765	693706	1876190
2004	2304288	2948400	3024000	2022451	2693174	266112	2209738
2005	2899411	2938723	1000339	248573	2376259	1051142	1752408
2006	3017952	3024000	3024000	1425514	154829	1079568	1954310
2007	1216253	3024000	2711923	1000944	976147	0	1488211

Minimum	15725	309658	319334	84672	0	0	121565
Mean	1766621	2406499	2384726	1966205	1695254	921715	1856837
Maximum	3024000	3024000	3024000	3024000	3024000	2989526	3018254

Method 7 If river flow > MEDIAN, then 33% of flow above the MEDIAN allocated up to a maximum of 2 m^3/s

Average Weekly Abstraction Volume (m^3/week)

	Jun	Jul	Aug	Sep	Oct	Nov	Mean
1970	1150330	1172102	1022112	1175126	1199318	515290	1039046
1971	524362	1131581	1209600	1209600	1103155	1209600	1064650
1972	728179	1158192	417917	261274	113098	40522	453197
1973	1003968	782611	1156378	1064448	587261	238291	805493
1974	528595	1209600	1209600	?	?	?	982598
1975	1208995	1195690	1139443	821923	1167264	428198	993586
1976	459648	1209600	1209600	1209600	1189642	1141862	1069992
1977	1209600	1209600	1209600	1209600	1199923	281837	1053360
1978	638064	1209600	1209600	754186	560045	249178	770112
1979	929578	1126138	1209600	1209600	1121904	569722	1027757
1980	1042675	1209600	1184803	1133395	126403	101002	799646
1981	1209600	1209600	1209600	1209600	1209600	1165450	1202242
1982	1011830	1039651	665280	56246	131242	38707	490493
1983	784426	942883	275184	289094	1053562	570931	652680
1984	43546	609034	931997	1207181	779587	91930	610546
1985	1209600	1209600	1209600	933811	0	80438	773842
1986	88906	685843	918691	1040256	1038442	0	628690
1987	27821	878170	860026	556416	394934	795312	585446
1988	122170	677981	1209600	1185408	693101	40522	654797
1989	1209600	1101946	518918	1209600	1209600	674352	987336
1990	377395	542506	1209600	808013	1129766	396749	744005
1991	348970	514685	1106179	224381	314496	713059	536962
1992	972518	1005782	1207786	1060214	1191456	1122509	1093378
1993	858211	188093	134870	800755	39312	80438	350280
1994	615686	1051747	909619	370742	1099526	971309	836438
1995	1208995	1209600	1037232	705197	569117	278208	834725
1996	325987	1209600	1170288	918691	127008	0	625262
1997	1081987	1203552	1014250	1209600	1199318	107050	969293
1998	10282	1095293	1037232	250992	406426	42941	473861
1999	956794	775354	824947	456019	0	501379	585749
2000	642298	1169683	1193270	1003363	772330	407030	864662
2001	342922	741485	815270	797126	688262	729389	685742
2002	726970	1209600	1209600	1209600	687658	48384	848635
2003	693101	385258	911434	1209600	1202947	333245	789264
2004	959213	1209600	1209600	942278	1130371	133661	930787
2005	1197504	1207786	462067	111888	996710	478397	742392
2006	1209600	1209600	1209600	651974	76810	501379	809827
2007	532224	1209600	1117066	471139	449971	0	630000
Minimum	10282	188093	134870	56246	0	0	64915
Mean	742090	1002758	993686	835834	728784	407635	785131
Maximum	1209600	1209600	1209600	1209600	1209600	1209600	1209600

Method 8 If river flow > MEDIAN, then 33% of flow above the MEDIAN allocated up to a maximum of 5 m^3/s

Average Weekly Abstraction Volume (m^3/week)

	Jun	Jul	Aug	Sep	Oct	Nov		Mean
1970	2540160	2757283	2495405	2709504	2697408	1097712		2382912
1971	1260403	2771798	3024000	2987712	2723414	2877638		2607494
1972	1756339	2664749	953770	452995	191722	101002		1020096
1973	2454883	1837382	2519597	2330294	1205366	490493		1806336
1974	1187222	3024000	3024000	?	?	?		2411741
1975	2870381	2759098	2719181	1748477	2628461	648346		2228990
1976	907200	2932675	3024000	3024000	2589149	2496614		2495606
1977	3024000	3024000	3024000	3024000	2613341	332035		2506896
1978	1459382	3019766	2668982	1506557	1049328	472954		1696162
1979	1815005	2457302	2932070	2958682	2515968	855187		2255702
1980	2378678	2996179	2625437	2295821	127008	151200		1762387
1981	3001018	3024000	3024000	3024000	2856470	2479680		2901528
1982	2230502	1861574	1342656	56246	131846	38707		943589
1983	1660781	2026685	491702	379814	2546208	1143072		1374710
1984	64714	1072915	1823472	2663539	1544054	111283		1213330
1985	3024000	2730672	3024000	1920845	0	88906		1798070
1986	88906	1306368	1801699	2215987	2208730	0		1270282
1987	27821	2053901	1879114	656208	624758	1908749		1191758
1988	261274	1588810	3024000	2681078	1043885	101002		1450008
1989	2969568	1907539	1140653	3014928	3009485	1221696		2210645
1990	583632	788659	3024000	1714608	2056925	490493		1443053
1991	500774	804989	2354486	240710	352598	1623283		979474
1992	2081722	2371421	2872800	2292192	2805667	2633299		2509517
1993	1679530	204422	277603	1215043	43546	171158		598550
1994	1324512	2071440	2098656	864864	2407104	2086560		1808856
1995	2398637	2976221	2155507	1215648	827366	480211		1675598
1996	809827	3024000	2384122	2040595	180230	0		1406462
1997	2444602	2760912	2134944	2879453	2803853	132451		2192702
1998	10282	2624832	1978301	472349	832810	103421		1003666
1999	2049667	1502323	1482970	976752	0	1097712		1184904
2000	1271894	2866752	2516573	2189376	1770250	837043		1908648
2001	630202	1640822	1904515	1772669	1241654	1302134		1415333
2002	1645056	3024000	3024000	2797805	1368058	52618		1985256
2003	1369267	720317	2159136	3024000	2725834	551578		1758355
2004	2191795	2834093	3016742	1642637	2472422	198979		2059445
2005	2791757	2802038	847930	232848	2281306	904176		1643342
2006	2924813	3024000	3024000	1113437	135475	931392		1858853
2007	1137024	3024000	2581891	857002	829786	0		1404950
Minimum	10282	204422	277603	56246	0	0		91426
Mean	1653523	2286144	2273443	1816214	1552522	816480		1733054
Maximum	3024000	3024000	3024000	3024000	3009485	2877638		2997187