Application of the River Ecosystem Management Framework to water allocation management

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Executive Summary

This report details results of technical work that has been undertaken to provide input into testing the application of the River Ecosystem Management Framework (REMF) methodology in planning water allocation. The purpose of the work is to evaluate whether River Environment Classification (REC) can be used to stratify rivers into different groups (management units) that can be treated similarly with respect to water management options.

The specific objectives of this study were to;

- determine whether significant differences in management regimes are appropriate among different management units.

- determine if options for general water management regimes result in consistent implications for water reliability and residual flows in rivers *within* a management unit.

The analyses carried out in order to answer these questions are complex because of the number of assumptions involved. In addition, many assumptions and decisions that have been made in the course of this analysis are essentially policy options. These options would require scrutiny by affected parties and a political decision making process, such as a regional plan, to ratify them. The study has chosen 'options' for the following decisions:

- Management objective including level of protection

- Minimum flow setting method

- Demand model

- Supply reliability criteria

The choice of these options results in consequences for both in-stream and out-of-stream values. The analysis is able to provide generalised information for each management unit including:

- Minimum flow

- Days of restriction per year

- Days of restriction in any month

- Probability of restriction events (cumulative days of restriction)

- Change in frequency freshes and duration of low flows

This study demonstrates that there are generalisable differences in the values and natural flow regimes among the management units. These differences are justification for managing the water resources of different management units differently. The study suggests options for general flow management regimes for each management unit. General flow management regimes apply a consistent minimum flow and total allocation to all rivers in a management unit. Consistency is attained by scaling these management provisions with a flow statistic, the mean annual low flow (MALF), to account for differences in river size. To be useful, the water availability based on a consistent management objective for instream values and a consistent set of reliability criteria for out-of-stream use, must also be consistent for all rivers in a management unit. Consistency across all these aspects of water management will allow a general framework for managing water allocation at the regional level, the implications of which can be understood. Such a framework also allows minimum flows and allocations to be set for rivers without detailed flow data, and for the consequence of this for reliability of supply to be predicted.

In general, the analyses showed that a consistent pattern of reliability of supply and residual flow behaviour can be expected within Glacial Mountain, Mountain and Hill rivers when subject to the same general flow management regime. This means that for these management units, the implications of the application of the management provisions can be explained in terms of the reliability of supply and residual flows. The results for the Volcanic and Soft Sedimentary management units are less convincing with wide variation in reliability of supply among rivers of the same management unit. The analysis does, however, provide some general guidance on the acceptable size of the total allocation for all the management units considered.

Water availability is highest in the Glacial Mountain management unit. Total allocation of up to 100% of MALF can occur in these rivers (assuming the demand model) without exceeding the nominated supply reliability criteria. Mountain and Hill management units have the next highest water availability. Allocations of 50% of MALF can be made without exceeding the reliability criteria. The seasonality and reliability of Mountain and Hill rivers is similar and therefore from a water resource point of view these two management units appear similar. Aggregation of the two management units to form a single unit is not justifiable, however, because there are differences in values between the two management units. Minimum flows have, therefore, been set differently in each management unit. Water availability is lowest in Soft Sedimentary and Volcanic management units. These management units fail to meet the reliability criteria at an allocation as low as 25% of MALF.

In broad terms, general water management regimes result in consistent implications for both water reliability and residual flows in rivers *within* a management unit. It should be borne in mind that the exact implications are dependant on, and sensitive to, the details of the general flow management regimes. This analysis has made many assumptions that would need to be considered and ratified by a proper consultative process. The implications of generalised flow management regimes for Glacial Mountain, Mountain and Hill rivers are reasonably predictable from statistics derived for rivers belonging to this group. The implications of a generalised management regime for Volcanic and Soft Sedimentary rivers are less predictable. The results of the analysis for all rivers, however, provide managers with important insights into the effect of differences in total allocation. It is also clear that total allocation should be managed differently *among* management units. The analysis therefore provides a clear justification for a regional framework for water allocation that varies minimum flows and total allocation between management units.

1 INTRODUCTION

This report details results of technical work that has been undertaken to provide input into testing the application of the River Ecosystem Management Framework (REMF) methodology in planning water allocation. The purpose of the work is to evaluate whether River Environment Classification (REC) can be used to stratify rivers into different groups (management units) that can be treated similarly with respect to water management options. Options for water management regimes deal with two critical aspects of water allocation management; minimum flow settings and total allocation (the total proportion of river flow that is allocated to abstraction).

In general, the environmental and resource use values of rivers differ markedly from each other. In addition, differences in environmental conditions between rivers drive differences in resilience to the effects of resource use. The REMF approach (Snelder and Guest 2000) recognises that, in an ideal world, water management decisions would be based on a detailed understanding of each river. However, given the number of rivers each regional council has to manage, this is unlikely and many management decisions need to be made in the absence of such knowledge. The principle idea behind the REMF is that management at a regional level can be based on river environment types. The classification of rivers groups or stratifies a region's rivers into a number of types; for example, in Canterbury a working number of nine types has been found to be useful. The types are defined using REC. The types of river are referred to as management units for management purposes. The approach assumes that, often, good data and understanding of various aspects of a rivers behaviour is available for some rivers within a type, but not all. Data and knowledge for each river can be aggregated by type and this generalised information can then be applied to all the other rivers of that type for which there is no information.

The approach recognises the need for regional water plans to provide a basis for management decisions in a rational and meaningful way in the absence of detailed studies everywhere, while recognising critical spatial variations in the characteristics, values and management needs of different types of rivers. Central to the approach, therefore, is the idea that plan provisions (purposes for management objectives, policies and methods) for managing rivers should vary spatially to reflect the natural differences between rivers at a manageable level of detail.

This study is a necessary first step in applying the REMF approach to water allocation. Once it is established that the regional management of water resources can be organised around management units, the REMF approach can be applied. This potentially offers a variety of advantages. A management regime can apply an equivalent set of provisions across all rivers in a management unit. This provides a consistent and certain approach to management. Data and information necessary for developing an understanding of water management is limited. The REMF approach aggregates data and knowledge for each management unit and this generalised information can then be applied to all the other rivers in the management unit for which there is no information. There is therefore a justifiable basis for setting policies and managing resources where site-specific data is limited. The REMF approach itself offers some potential improvements to plan structure by organising management around management units. The stratification of a regions river resource into management units enables the plan to identify values more specifically than when rivers of the region are treated as a single group. As a consequence objectives can be developed that are more specific and relevant to the particular environments being managed.

2 AIM OF THE STUDY

This study aims to test the application of the REMF approach to management of water resources of rivers in a region. The specific objectives of this study were to;

- Determine whether significant differences in management regimes are appropriate *among* different management units.

- Determine if options for general water management regimes result in consistent implications for water reliability and residual flows in rivers *within* a management unit.

- Use the approach to generate a series of management regime options that can be used in the policy development process.

3 MANAGEMENT OF RIVER WATER RESOURCES

Management of river water resources is complex with many competing demands and relatively complex technical issues. Environmental values of rivers (ecosystem, recreation, natural character etc) are sustained by natural flow. Water, however, also has value for out-of-stream uses such as power generation and agricultural production. Where abstraction of water occurs there is a net reduction in the natural flow over time. The hydrograph (graph of river flow over time) is reduced by the abstraction rate (see Figure 1). The flow remaining in a river after abstraction is the residual flow. The maximum possible rate of abstraction for out-of-stream use is called the total allocation, which is set by council policies or by conditions on resource consents.

In general, river flow is usually more than sufficient to sustain values allowing some water to be abstracted without adversely affecting such values. During periods of low flow, however, flow can become a limiting factor for these values. To ensure values are sustained, water management regimes reduce and ultimately suspend the abstraction rate as the flow reaches a prescribed minimum flow setting. As the residual flow in a river approaches the minimum flow, abstraction restrictions are imposed to ensure that the minimum flow is not breached. The abstraction rate will often be less than the total allocation to ensure minimum flows are not breached. The hydrograph below (Figure 2) shows the effect of imposing a minimum flow. Note how the abstraction rate (which is the difference between the residual flow and the natural flow) varies in order to ensure the minimum flow is not breached.

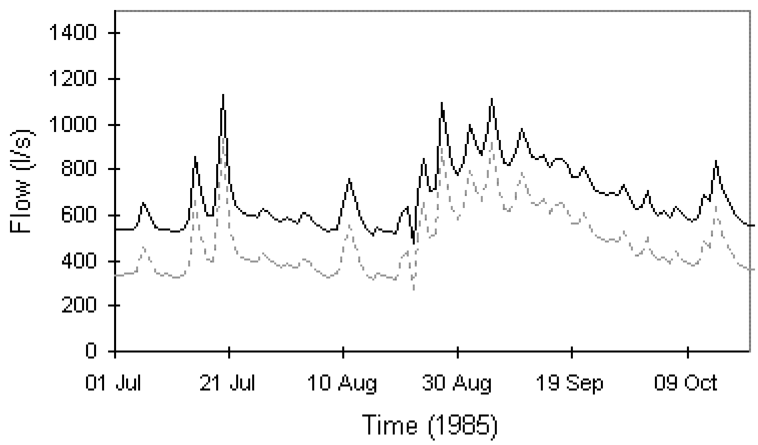

Figure 1: A hydrograph for a river showing a net reduction in flow due to abstraction. The upper (black) line is the natural flow. The lower (grey) line is the residual flow caused by the abstraction at a rate equal to the total allocation of water for out-of-stream uses.

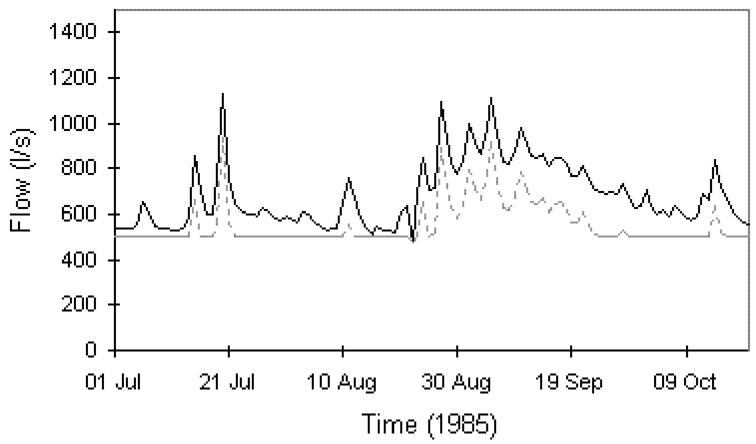

Figure 2: Hydrograph showing the effect of abstraction on residual flows. The upper (black) line is the natural flow. The lower (grey) line is the residual flow. The abstraction rate is the difference between the lines. The abstraction rate varies over time to ensure that the nominated minimum flow (here 500 l/s) is not breached. Note that the natural flow does descend below the minimum flow at one point.

Minimum flow settings mean that river resources will not always meet the total to out-of-stream users. The ability to meet the allocation is referred to as the reliability of supply. The reliability of a river resource is essentially a function of the rivers hydrology. Rivers that have flows that are high during the period of peak water demand relative to the minimum flow setting are more reliable than the reverse. This dynamic aspect of rivers, and the fact that it varies significantly between rivers is a source of complexity for management. Figure 3 shows how the abstraction rate in the above plot has been restricted (relative to the total allocation) over time so that the minimum flow is not breached.

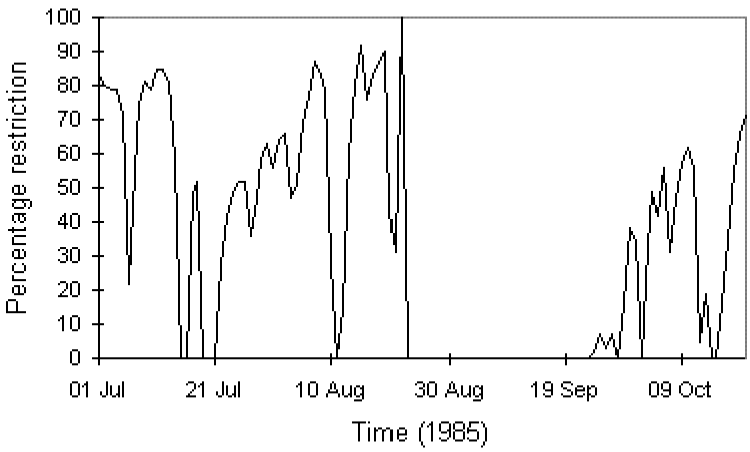

Figure 3: The percentage restriction (i.e. the % difference between the allocation and the abstraction rate) for the period of record shown in Figure 2. Where the percentage restriction is 100% there is no abstraction (i.e. the natural flow in the river is equal to, or less than, the nominated minimum flow). When there is no restriction (the percentage restriction is 0%) the abstraction rate is equal to the allocation (i.e. the natural flow in the river is high).

An additional source of complexity in managing allocation arises because, for a given minimum flow, reliability decreases as allocation increases. This is because the frequency and duration of the residual flow descending to the minimum flow increases, as the amount allocated gets greater.

In order to manage the water resource, managers have the ability to control two variables; the total allocation and the minimum flow setting. We referred to this here as the management regime. Because flows cannot be predicted with much certainty, the effect of abstraction on residual flows, and the risk of restriction to out-of-stream abstractors, can not be assessed deterministically. Instead it is assumed that the natural flow regime will remain the same in the future. Therefore the effects of different management regime options can be assessed by superimposing different allocations and minimum flows on the historic flow series. It is generally assumed that the resulting modified flow series is representative of the future conditions under the management options specified provided that other catchment conditions stay constant. From this analysis a thorough understanding of water availability (the maximum possible total allocation given an instream management objective and a set of reliability criteria) and the likely frequency, duration and magnitude of restrictions (referred to here as reliability of supply), and the behaviour of the residual flows, can be developed. This understanding is then carried forward to the consultative and decision making process from which a specific option is chosen to become the "management regime" for the river.

4 STUDY METHOD

4.1 Approach

To achieve its objectives, the study developed methods to apply a general flow management regime (comprising a consistent minimum flow criteria and a consistent total allocation) to rivers that are grouped together to form a given management unit. An analysis was then undertaken to determine whether there is reasonable consistency in the reliability of supply and behaviour of residual flows for rivers within this management unit when subjected to the same management regime. We then compared these variables among different management units to illustrate how the REMF approach might improve our ability to manage the water resource.

The steps in the study approach are therefore:

- Stratify the region's rivers into management units using REC;
- Select a set of representative rivers for each management unit, which have a flow record that is either natural or can be 'naturalised';
- Develop a justifiable instream management objective (MFE 1998) for each management unit;
- Develop a model of water demand;

- Develop minimum flow criteria for each management unit that can be 'scaled' to take into account differences in river size;

- Develop a set of criteria for reliability of supply for assessing various management options;

- Run a series of analyses to examine how reliability of supply varies for different levels of total allocation for each management unit.

4.2 Stratification the regions river resources into management units

Snelder et al. (2000) applied the REMF approach to the management of water quality in Canterbury. This work considered that a primary stratification of rivers in a region should be made on the basis of two factors that are unchanged by human activities and which are primary determinants of the properties of rivers; source of flow and geology (see Snelder and Guest 2000). Rivers that are grouped according to these principles are called 'core management units' because they are differentiated using factors that are fundamental determinants of environmental conditions. The REC was used to define nine core management units for the Canterbury Region and map their location (Figure 4). The characteristics and values of these management units are summarised by Snelder and Guest (2000).

The factor 'source of flow' defines groups that behave similarly with respect to their hydrology. The hydrological regime controls the availability of water for resource use including the seasonality of flows and the variability of flow from week to week and, therefore, the reliability of the river as a water supply. Hydrology is also a fundamental controller of the differences in values due to its dominant effect on a river's physical conditions (see discussion in Snelder and Guest 2000). Further subdivision of source of flow on the basis of geology improves the discrimination of differences in hydrology and further defines differences in values. For example, geology controls substrate composition, which in turn, controls the available habitat for organisms such as trout and benthic invertebrates. Geology also controls aspects of water quality, such as nutrient concentrations, which is directly linked to many values such as aesthetics and recreation (Biggs 2000).

4.3 Representative rivers

Hydrological data for the present analysis was fairly limited. This highlights a common problem facing water mangers at a regional level. We had data sufficient to consider five of the nine core management units: Glacial Mountain Hard Sedimentary (referred to here as Glacial Mountain), Mountain Hard Sedimentary (referred to here as Mountain), Hill Hard Sedimentary (referred to here as Hill), Low Elevation Volcanic (referred to here as Volcanic), and Low Elevation Soft Sedimentary (referred to here as Soft Sedimentary). Even within these five management units the data was limited, particularly because many flow recorder sites are affected by abstractions and could not be converted to natural flow records, a prerequisite for use in our analysis. Table 1 details the flow sites used by the study and their locations are mapped in Figure 5.

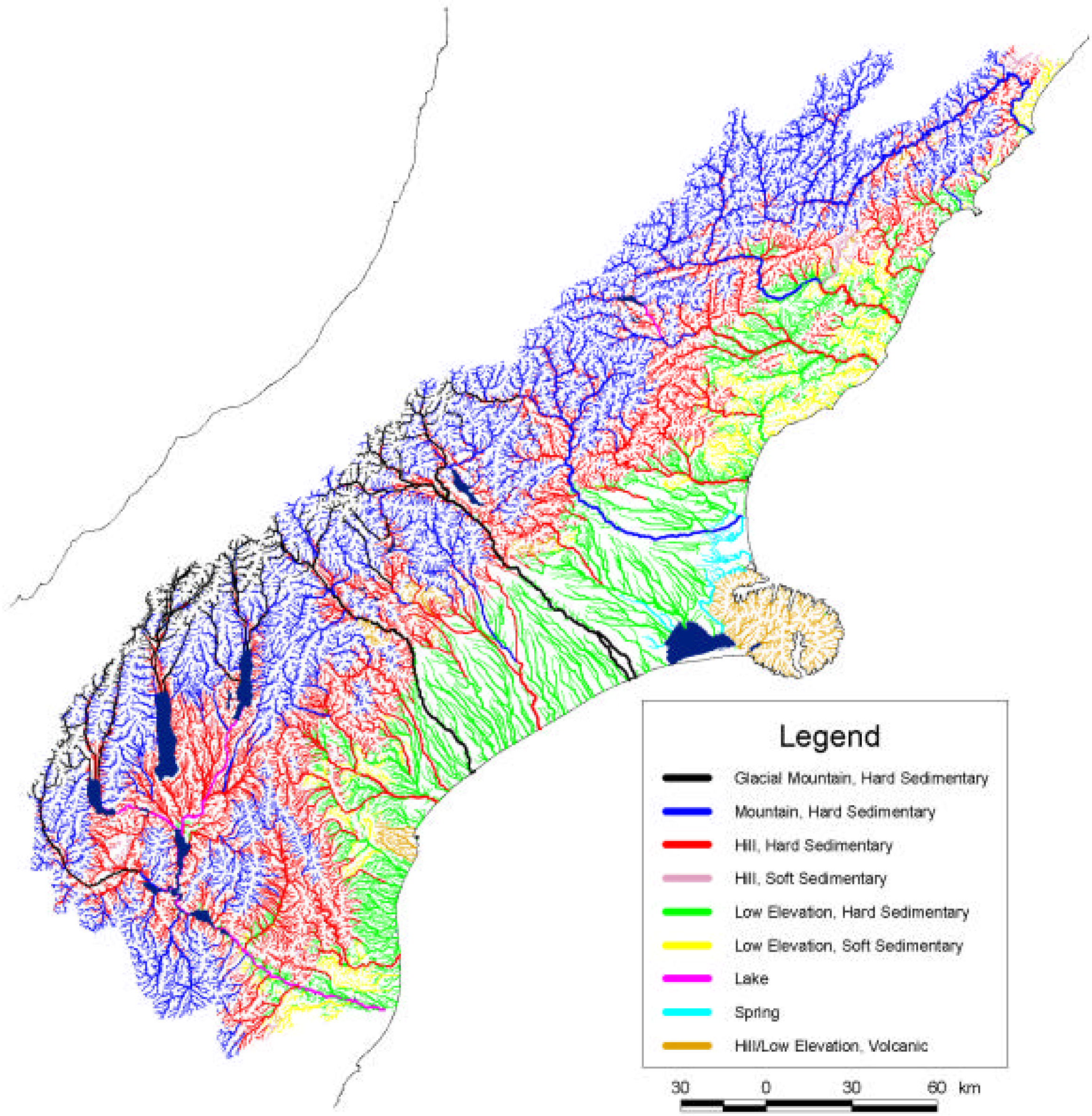

Figure 4: Nine core river management units for Canterbury.

Table 1: Flow sites used in the study for each of five main management units.

Management unit	River	Site name	Catchment area (km^2)	Record duration	Mean flow (l/s)	MALF (l/s)
Glacial Mountain	Bealey	Arthurs Pass	16	15	2555	528
	Rakaia	Fighting Hill	2560	16	212788	77401
	Rangitata	Klondyke Corner	1461	21	101448	39957
Mountain	Clarence	Jollies	440	40	15062	3320
	Waiau	Marble Point	1980	32	98840	31160
	Waimakariri	SHB	3210	27	130780	45948
Hill	Ashley	Gorge	472	27	12359	2053
	Hurunui	Mandamus	1060	43	53124	17166
	Orari	Gorge and Silverton	521	33	10604	2815
	Pareora	Hutts	424	14	3783	781
	Selwyn	Whitecliffs	164	36	3357	773
	Waihao	McCulloughs Bridge	488	15	3505	365
	Waipara	White Gorge	370	12	2973	82
Volcanic	French Farm	French Farm Valley Road	7	9	114.8	14
	Hukahuka	Lathams Br	12	12	221.1	31
	Kaituna	Kaituna Valley	40	13	609.5	20
	Reynolds	Brankins Br	3	7	81.97	18
Soft sedimentary	Awamoko	Georgetown	115	16	244.6	2
	Stanton	Cheddar Valley	42	32	517.5	7
	Stony Creek	Forbes Rd	6	6	36.57	0.1

4.4 Instream management objectives

The REMF methodology differs only slightly from a ‘standard’ planning approach in that it focuses analysis by initially stratifying rivers into management units. In so doing, it increases the ‘resolution’ of the analytical process. The REMF analysis starts by identifying values within each management unit and then provides the planning process with options for the ‘purposes for management’. The idea of the purpose for management is that, from amongst all the values present in a management unit, the decision making process must select specific values that management will seek to sustain. This recognises that not all values will be specifically managed for. The REMF approach encourages explicit and transparent choices about what a unit, or part

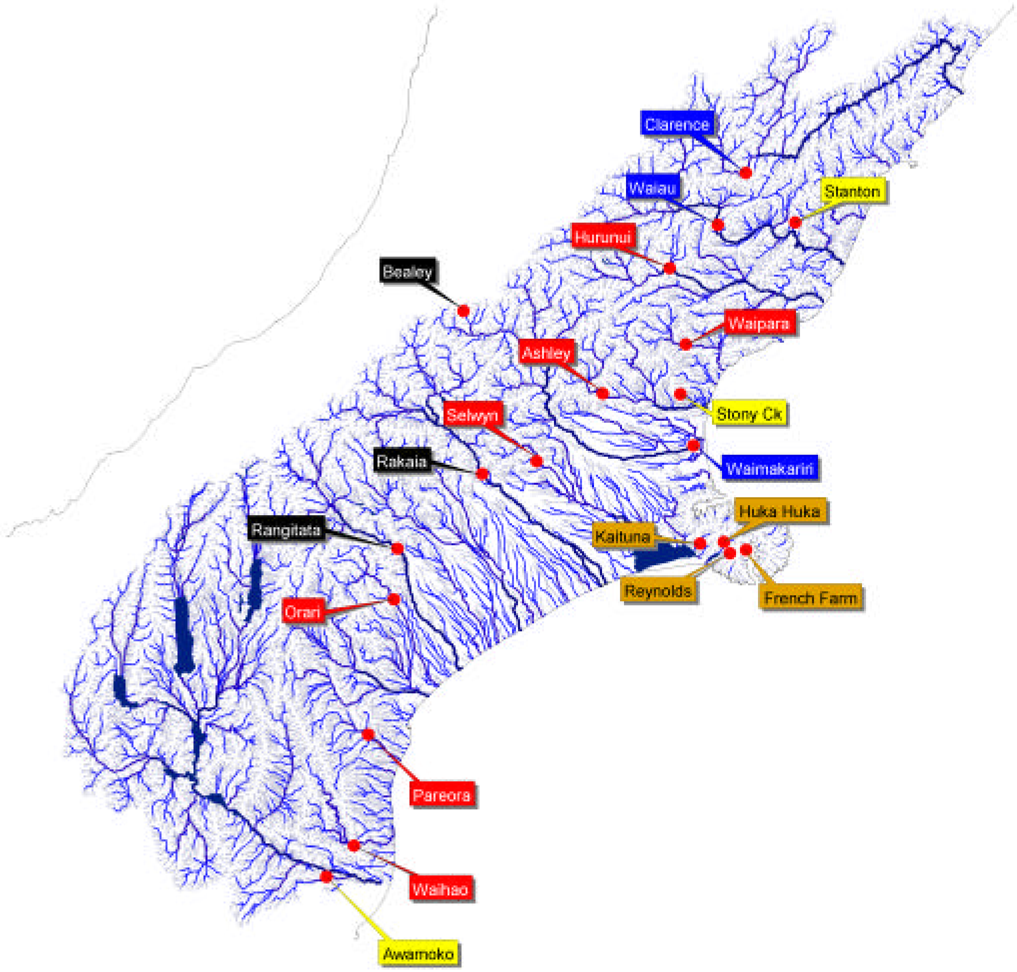

Figure 5: Location of flow sites used in the study. The site names are colour coded according to the management units they represent using the same key as shown in Figure 4.

of a river within a unit, will be managed for and incorporates the concept of 'significance' in making choices about management goals (Snelder and Guest 2000). The REMF process then selects a <u>critical value</u>[1] and uses this to develop an <u>Instream Management Objective</u> (MFE 1998, Volume A) referred to here as the <u>objective</u>. The critical value is the value, chosen from the purpose for management, which is most sensitive to the issue being analysed which here is change in flow. The objective defines an <u>environmental state</u> that will sustain the critical value at a specific level of protection. The critical value is used to represent the purpose of management of the

[1] The REMF approach outlined by Snelder and Guest (2000) referred to a 'surrogate' value. We consider the use of surrogate is misleading and refer to the 'critical' value.

management unit as a whole. It is assumed that, provided the most sensitive value is provided for, protection of other values will also occur.

Snelder and Guest (2000) identified ecological values for the core management units for Canterbury. Options for the purpose for management, critical values and objectives for water quality management were developed for each of the core management units for ecological values. Snelder and Guest (2000) acknowledged that the inclusion of a wider range of values (e.g. recreation, natural character) would potentially result in different critical values and objectives. A thorough identification of values and analysis of critical values and objectives may result in variations in the management objectives suggested here. The principles in developing objectives, however, would remain the same and we consider the analysis we carry out here is sufficiently robust to test the approach.

4.4.1 Glacial Mountain and Mountain Management Unit

Glacial Mountain and Mountain rivers generally have swift deep flows in the 'centre' of their main channels with periodically dry braiding across the rest of the flood plain. The central channels are relatively inhospitable to fish. Suitable fish habitat is often restricted to the edges of the main channel and the smaller braids. Because of these hydraulic characteristics, reduction in flow tends to keep the available habitat constant down to some critical flows, the location of habitat moving toward the centre of the channel as depths and velocities reduce. As a consequence a large proportion of the flow can be abstracted from Mountain and Glacial Mountain rivers without significant change in the available fish habitat. Reductions in flow of this magnitude, however, would impact on other values. For example, flows decrease, depths in the main channel and riffles will also decrease, affecting passage for jet boats and kayaks and therefore affecting recreational values. The number and size (wetted perimeter) of the main channel and braids will also decrease. This potentially affects the natural character of the river at low flow. We therefore assume that recreation and natural character are the critical values for these management units.

We have based options for objectives on retaining a proportion of an hydraulic characteristic occurring naturally at MALF. This study has used the minimum passage depth, which is the maximum depth occurring in the shallowest cross sections (generally cross sections at riffles and at 'divergences' where a single channel form two braids) as the critical hydraulic characteristic. It is assumed that an acceptable retention of minimum depth of passage in the main channel is nine-tenths of that occurring at the mean annual low flow. The minimum depth of passage will be highly correlated with other hydraulic characteristics such as velocity, width and number of braids. It is emphasised again that the objective of retaining nine-tenths of the minimum passage depth at MALF is a nominal criteria presented as a 'policy option' and the acceptable retention could be varied. In addition, other characteristics could be used for setting objectives or a 'composite' criteria based on retaining acceptable proportions of hydraulic characteristics could be developed.

4.4.2 Hill Management Unit

Snelder and Guest (2000) suggest the maintenance of brown trout habitat as a critical value for hill rivers. However, these units are also valued as recreation resources, particularly for swimming. The assumption is made here that trout are a reasonable critical value in terms of water quantity and flow management, and provision for this value will retain sufficient high quality water for swimming. In a complete development of management objectives, the validity of this assumption would need to be considered against other recreation and natural character values. Options for management objectives for hill rivers therefore define a range of criteria for retaining trout habitat.

A number of assumptions are generally necessary in establishing objectives for flow management. For gravel bed rivers (such as we are dealing with in this Hill management unit) it is assumed that the hydraulic habitat (depth and velocity) available during low flow periods limit fish populations. Minimum flows, therefore, are nominated to retain some level of hydraulic habitat and ensure the sustainability of the fish population. It is also assumed that abstraction has little or no effect on flow variability or 'flushing flows', although this assumption needs to be checked (particularly for low intensity events). Flow variability limits the total biomass of algae or rooted plants (macrophytes) in a river (see Snelder and Guest 2000 for a detailed explanation). Plant biomass affects water quality parameters that are an important aspect of sustaining many values such as fish or recreation. It is therefore assumed that, in the Hill management unit, abstraction does not affect values through water quality effects.

Levels of protection can be related to various measures of hydraulic habitat for trout. For example, Jowett (1993) suggested an objective based on retaining a proportion of the trout habitat occurring naturally for rivers in the Wellington region such as retaining two-thirds of the trout habitat that occurs naturally at MALF. It is emphasised that two-thirds is a nominal value presented as a 'policy option' and the actual retained habitat could be varied.

4.4.3 Volcanic and Soft Sedimentary Management Unit

Assumptions for establishing objectives for Volcanic and Soft Sedimentary differ from Hill and Mountain rivers. For example, recreation and natural character values are less significant in these management units and might focus more on their ecological values. We assume ecological values are more sensitive to changes in flow than other values in these management units. These river types have fewer floods and therefore tend to support greater plant biomass. It is likely that water quality effects on ecological values, rather than hydraulic habitat, will become more limiting as flows decrease (see Snelder and Guest 2000 for a detailed explanation). Objectives therefore might seek to maintain limiting water quality parameters such as dissolved oxygen (DO) above 6 mg/l.

4.5 Minimum flow setting methods

There are a variety of methods for setting minimum flows, which are described in MFE (1998, Volume B). The methods range from simple to relatively complex with corresponding low-high resource and information needs. The choice of which minimum flow setting method is used is dependent on the significance of the instream resource and the value of out-of stream use of the water and therefore the level of certainty that needs to be applied to management.

The simplest method for setting minimum flows is an historic flow method. Historic flow methods use a flow statistic such as the 1 in 5 year 7-day low flow (e.g. Otago Regional Plan (ORC 1999) or a flow that is equalled of exceeded for a given proportion (e.g. 95%) of the time. Historic flow methods are not directly related to a given management objective. They apply the assumption that existing values will be sustained by a flow that has been experienced before in the historic flow record. The approach is not, therefore consistent with the REMF methodology. Another problem with the method is that the level of protection afforded by the minimum flow is variable because flow regimes are variable among different types of rivers. Thus the 'effects' of a flow statistic used to set a minimum flow will also vary among rivers. For example a 1 in 5 year 7-day low flow in a stable spring fed stream may be a flow that is very similar to a normal flow. On the other hand the 1 in 5 year 7-day low flow in a highly variable hill-fed river may be very low.

The most detailed approach to setting flows is the Instream Flow Incremental Method (IFIM). The method describes the change in depth, width and velocity, which together define habitat, with change in flow. A particular feature of many hydraulic characteristics such as depth, width and velocity is that they do not change linearly with a change in flow. The change of instream habitat with flow, therefore, is also non-linear. As a result, a set reduction in flow may result in a larger reduction in available habitat in one stream than another stream. IFIM overcomes the problem of non-linear habitat/flow relationships by developing mathematical descriptions of these relationships between habitat and flow that are specific to the critical river reach being considered. Where rivers are smaller, the defined minimum flow will be proportionally larger because the available habitat in smaller rivers tends to reduce at a higher rate with change in flow than in larger rivers.

In this study we use methods of minimum flow setting that are between historic flow methods and IFIM in terms of complexity. There are a number of methods that relate historic flows to a specified objective. The Tennant and Modified Tennant method are based on general relationships between mean annual flow and specific criteria for depth and velocity preferences of trout (MFE 1998). We use similar approaches to setting minimum flows here by relating a proportion of MALF to specific objectives such as retaining a proportion of a hydraulic characteristic or a proportion of habitat. Using a proportion of MALF has the effect of 'scaling' the minimum flow (i.e. minimum flow scales with river size). The scaled minimum flow can therefore, be equivalent for rivers of different size within a given river type of management unit. Superficially this appears to be similar to historic methods. The difference is that the scaled-minimum flow that is set can be different proportions of MALF for different management units. This allows for differences in the hydrological regimes between management units, and therefore in the 'effect' of MALF to be taken into account in setting the minimum flows. The method also allows the proportions of MALF to be set so that the non-linear relationship between habitat and flow is taken into account by generalising flow versus hydraulic geometry or habitat relationships.

4.5.1 Glacial Mountain and Mountain Management Unit

As discussed in Section 4.4.2, we nominated minimum depth of passage for salmon as the objective for this river type. Mosley (1982) developed a relationship between minimum depth and flow for Canterbury gravel bed rivers based of surveys in three rivers. It is noted that of the rivers surveyed two (Ashley and Hurunui) are classified as Hill rivers and only the Rakaia is a Mountain river. Mosley was confident, however, that the hydraulic characteristics of these rivers are similar and a generalised non-linear relationship could be derived by aggregating the data from all three rivers.

Mosley (1982) surveyed the maximum depth in the shallowest cross sections and referred to this quantity as the minimum passage depth (D_{min}). A relationship between flow for the whole river (Q_t) and D_{min} was derived from the survey data:

$$D_{min} = 0.08\, Q_t^{0.27}$$

This relationship was used to calculate the minimum depth at MALF for the Mountain and Glacial Mountain rivers. As discussed in Section 4.4.2, the option proposed here is to retain 9/10^{ths} of this depth as the minimum flow. We therefore back calculated a minimum flow by setting D_{min} to 9/10^{ths} of D_{min} at MALF. From Mosely's relationship, Q_t to retain depth at 9/10^{ths} of D_{min} is 68% of MALF[2]. The option we present here for evaluating the minimum flow is therefore 68% of MALF.

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[2] In this report we consistently use fractions to represent the objective. For example the objective in the Hill management unit is to retain 2/3^{rds} of the habitat available at MALF. The flow required to achieve this is expressed as a percentage of MALF. Note also the similarity in

4.5.2 Hill Management Unit

As discussed in Section 4.4.1, we nominated retention of two-thirds brown trout habitat available at MALF as the objective for hill rivers. We use a method for setting minimum flows derived using Instream Flow Incremental Methodology (IFIM) Jowett (1993) suggested that an option for such an objective could be to retain two-thirds of the trout habitat that is available at MALF. Jowett (1993) found that trout habitat declines to zero as the flow falls below MALF for a range of rivers in the Wellington region. In no cases did two-thirds of MALF retain less than two-thirds of the habitat. In general the habitat of larger rivers in the Wellington region decreased less rapidly as flow starts to reduce below MALF. The retention of two-thirds of MALF was therefore 'conservative' as in all cases it retains at least two-thirds of the trout habitat at MALF. We have therefore applied this method to the Canterbury management unit, acknowledging that a regional habitat/flow relationship would need to be derived for Canterbury for this method to be justifiable.

4.5.3 Volcanic and Soft Sedimentary Management Unit

We assume that minimum flows for Volcanic and Soft Sedimentary management units need to be set to maintain water quality for ecological (critical) values. A range of techniques exist for setting minimum flows to achieve temperature, DO and pH criteria (MFE 1998). These have been incorporated in a minimum flow setting tool called WAIORA (Kingsland and Collier 1998). This tool has been developed for use in the Auckland Region although the techniques it incorporates are applicable to elsewhere. Essentially the tool takes a user defined critical value and evaluates a minimum flow to protect this value. WAIORA evaluates minimum flows required to achieve a range of habitat criteria; (hydraulic habitat, temperature and DO) separately. It then selects the highest flow calculated (i.e., the limiting habitat parameter) as the minimum flow.

To date work on low elevation streams in the Auckland region has found that DO is the most limiting habitat parameter. In general flows below MALF cause an exceedance of a generalised DO criteria (6 mg/l) for the protection of native species (Alastair Smale ARC pers. comm.). We assume that we can transfer this 'guideline' to the Low Elevation Volcanic and Soft Sedimentary rivers of the Canterbury region acknowledging application of such a method to Canterbury requires region-specific work to be justified.

the minimum flow for Glacial Mountain and Mountain rivers and Hill rivers of 68% and 67% respectively is coincidental and both minimum flows arise from very different objectives.

4.6 Reliability of supply analysis

When reliability of supply information is provided to water users (e.g. irrigators) it is often based on a daily time series of actual demand with information on when that demand might be restricted. This study has used statistics to summarise this detailed information time series data about a particular river resource to describe the supply reliability and residual flows for each management unit. Reliability and residual flow statistics are derived by combining a time series of natural flow with a time series of likely demand. These statistics can then be compared between rivers to determine if a pattern for different management units exists.

The computer program Low Flow Analysis Tool (LowFAT) (Snelder et al. 1999) assists decision-making by enabling the user to superimpose scenarios for water management regimes (by specifying allocation and minimum flows) on natural or naturalised flow records. Statistics are generated from the time series that result from subtracting the allocation rate from the natural flow. The output from LowFAT provides information on the frequency and duration of restrictions for the out-of-stream users and on residual flows for in-stream values (duration and frequency of residual river flows).

4.7 Demand model

To undertake a reliability of supply analysis we made assumptions concerning the variation in demand (the proportion of the total allocation that is actually required) at any time. The assumption recognises that irrigation (the principle use of water in Canterbury) varies over the irrigation season in accordance with weather conditions and crop needs. A number of possible 'shapes' to the demand curve are possible depending on the crop, local climate and irrigation systems. Significant variation between years also occurs due to variation in weather conditions. We analysed a 28-year time series of daily rainfall and evapotranspiration data from the Winchmore Research Station to determine the relative demand for each month from September to April. From this we developed a representative demand curve (Figure 6). Demand has been assumed to 'ramp up' from September to full allocation in December/January and 'ramp down' to no irrigation from May to August. This 'curve' was modelled as stepped increases in the demand as a percentage of the total allocation (see Figure 6).

We have assumed that the allocation is a single 'block' and the minimum flow applies to this entire block. In reality the total allocation block would be made up of a number of individual consents. Often different minimum flows can be applied to these individual consents and some 'secondary consents' may have 'flow sharing' conditions. These more complex management regimes are generally developed for a large individual resource for which there is a lot of competition for the resource. The demand model we have used here is a simplified form of these more complex individual management regimes to compare within, and contrast between, management units.

The demand is scaled for each site to allow for differences in river size by expressing total allocation as a proportion of MALF. This allows the abstractions at each site to be equivalent compared to the available flow and allows comparisons between all sites to be shown on a common scale.

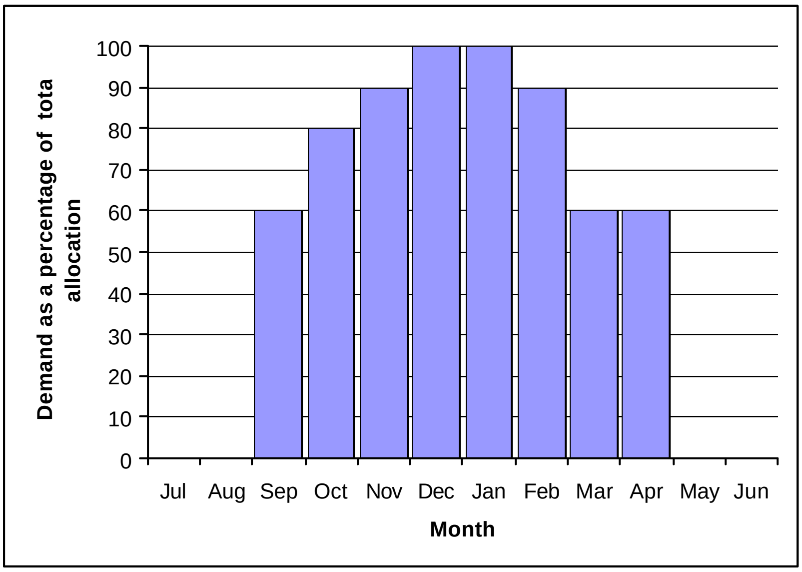

Figure 6 Demand model assumed by the LowFAT analysis.

4.8 Reliability of supply criteria

Reliability of supply criteria are based on the acceptability of restriction in allocation for out of stream users. Restriction can be expressed as a 'level' or percentage by comparing the abstraction rate with the total allocation (see Figure 3). Because demand varies by month, the acceptability of restriction, expressed as a proportion of total allocation, is effectively varying by month. For example, a restriction of 40% of total allocation in September would have no effect on abstractors because demand is only 60% of total allocation.

Reliability of supply for out-of-stream water users could be specified in terms of:

(1) the <u>frequency</u> of restriction (how often the demand cannot be met)

(2) the <u>severity</u> of restriction (the percentage of the demand that cannot be met)

(3) the <u>duration</u> of restriction (the cumulative days of any restriction) and

(4) the timing of restriction.

Criteria that combine all four of these factors could be used to define acceptable thresholds below which irrigators start to experience difficulty. The reliability of supply criteria will vary with the type of use of the water. Criteria for defining acceptable thresholds are being developed for ECan by Lincoln Environmental. Our analysis is based on early stages of this work and the criteria we assume here are therefore 'nominal'. For the purposes of this analysis, we have simplified the criteria to exclude severity. We therefore define reliability of supply criteria based on any level of restriction in demand. The timing of restrictions has been applied over the whole irrigation season (September to April). This timing is consistent with intensive pastoral farming where there is demand for irrigation over the whole season.

We have considered a range in total allocation in order to describe a range in frequency and duration of restriction. This allows the exact frequency and duration criteria to be applied later. In order to keep the output to manageable levels, we have summarised the analysis using only one set of possible criteria these are:

- Restricted, on average, no more than 10% of days for the irrigation season
- Restriction of no more than 20% of days in the most restricted month.
- Restricted on average, for only one event of 7 consecutive days per year
- Restricted on average, for only one event of 20 consecutive days every 5 years

5 ANALYSIS

5.1 Seasonality of flow regimes

Our first analysis considered whether the rivers within each management unit followed similar seasonal patterns or whether these season patterns varied significantly between management units. This preliminary step establishes that the hydrology of rivers within a management unit behave similarly. We analysed the median monthly flow for the sites shown in Table 1 and expressed this as a proportion of median annual flow. The statistic expresses the seasonality of the flow regime in a way that all sites can be compared on the same graph because flows are 'normalised' by dividing be the mean flow. The results are shown on Figure 7 arranged by management unit.

Figure 7 shows that there is considerable similarity in flow regimes for rivers within each management unit and significant variation in flows among management units. A number of features in Figure 7 are important. Firstly there are a number of 'spikes' caused by large flood events in some months combined with a relatively short period of record for that site. In particular, there are spikes in the records from Soft Sedimentary rivers for December and March. A similar spike in December occurs for some of the Hill river records.

There is general similarity in seasonality for rivers within each management unit. Glacial Mountain, Mountain and Volcanic rivers in particular show very consistent patterns within their respective units. The greatest spread occurs in the Hill management unit. This is possibly because this unit includes rivers that cover a relatively wider range of environmental conditions. For example, heterogeneity in geology and land cover within this group is relatively large. In addition, this management unit is the most geographically diverse grouping and there is, therefore, the possibility that climate variation across the region is causing some variation in seasonal pattern.

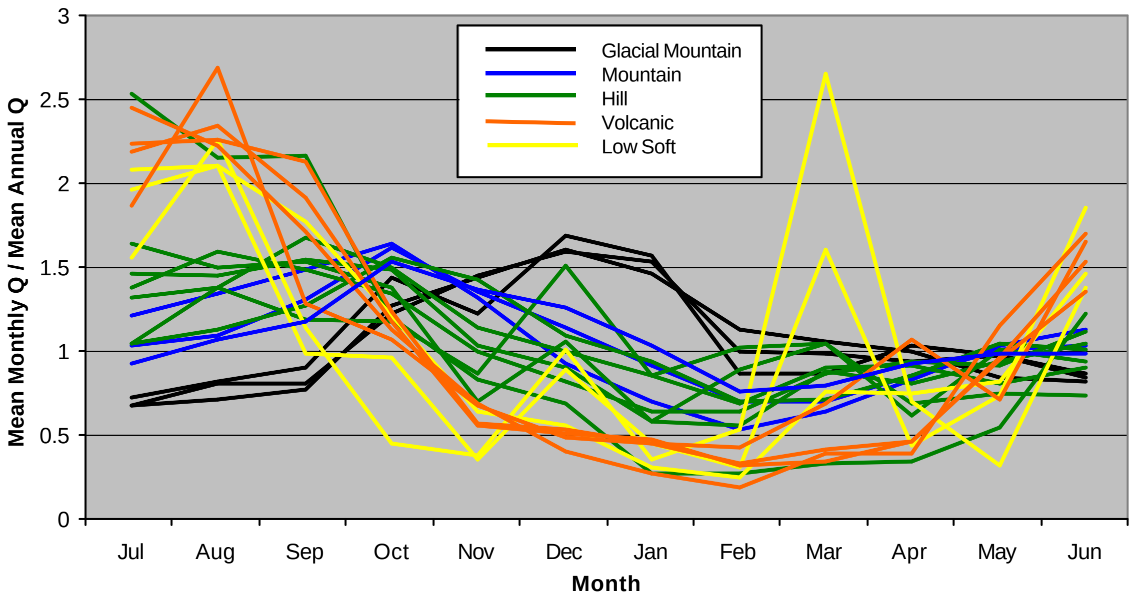

Figure 7: Mean monthly flows as a proportion of mean annual flow

Figure 7 also shows that there is significant difference in the seasonality of flow between management units. Rivers in the Glacial Mountain management unit have peak flows in December when solar radiation is highest and snowmelt is maximised. Low flows for Glacial Mountain rivers are in winter when most precipitation is 'locked' in their catchments as snow. Mountain rivers have less area of permanent snow field than Glacial Mountain rivers. Their peak monthly flows occur in October and then reduce to a late summer low flow. Mountain rivers also have the majority of their winter precipitation locked as snow and therefore have a second low flow period in winter. Volcanic and Soft Sedimentary rivers show the reverse seasonal regime. Flows are highest in winter when precipitation is highest and evapotranspiration is lowest. Hill rivers are a mid point on a continuum between the Mountain and Volcanic and Soft Sedimentary management units. Some precipitation in winter is stored as snow meaning they have relatively lower winter flows than Volcanic and Soft Sedimentary rivers. Flows are sustained into spring by snowmelt and the spring northwestly season that tends to enhance rain fall in higher elevations relative to low elevation. The spring peak flow, however, drops away faster than mountain rivers meaning low flows occur in January, a month or so earlier than Mountain rivers.

The seasonality of the flow regime shows why Glacial Mountain and Mountain rivers are better water resources that other management units. These rivers, apart from being larger sources of water, have peak flows extending well into , or in the case of Glacial Mountain rivers through, the period of peak demand (see Figure 7). The other management units are in their low flow period at the time of peak demand and are therefore expected to be less reliable water supplies.

5.2 Days of restriction analysis

A ‘days of restriction’ analysis shows the number of days that there is any restriction of the demand. The analysis is carried out by counting the number of days that the available abstraction rate is less than the demand for that time of year. The results are presented on Figure 8, which shows the days of restriction per season for all management units for a range of total allocation. The total allocation is depicted as a percentage of MALF so that all sites can be shown on the same graph. Lines of best fit have been fitted to show the trends in the data.

The annual analysis shows a broad overview of the reliability of each of the management units across a range of Total Allocation. The days of restriction is essentailly a measure of water availability, given the set minimum flow and demand model. The combination of the demand model (Figure 6) and seasonal pattern (Figure 7) results in a marked difference in water availability for any given level of allocation. The water availability decreases from for the management units in the flowing order; Glacial Mountain, Mountain, Hill, Soft Sedimentary and Volcanic.

The clustering of the data points for each management unit about their corresponding trend line provides an appreciation of the consistency of reliability among rivers. Glacial Mountain rivers show a high level of consistency with all data points falling close to the trend line. The days of restriction are therefore similar across all rivers in this management unit for a given level of total allocation. Mountain and Hill management units have lower consistency. The variation in the number of days of restriction within these management units, is however still relatively small. There is wide variation in the number of days of restriction for the Soft Sedimentary and Volcanic management units. Volcanic rivers, in particular, show wide variation. This indicates that the rivers in this management unit have hydrological regimes that vary considerably from each other. The reason for this is likely to be the relatively small catchments, very variable deeper geological structures, and variation in microclimate across this complex management unit (Graham Horrell, Environment Canterbury, pers. comm.)

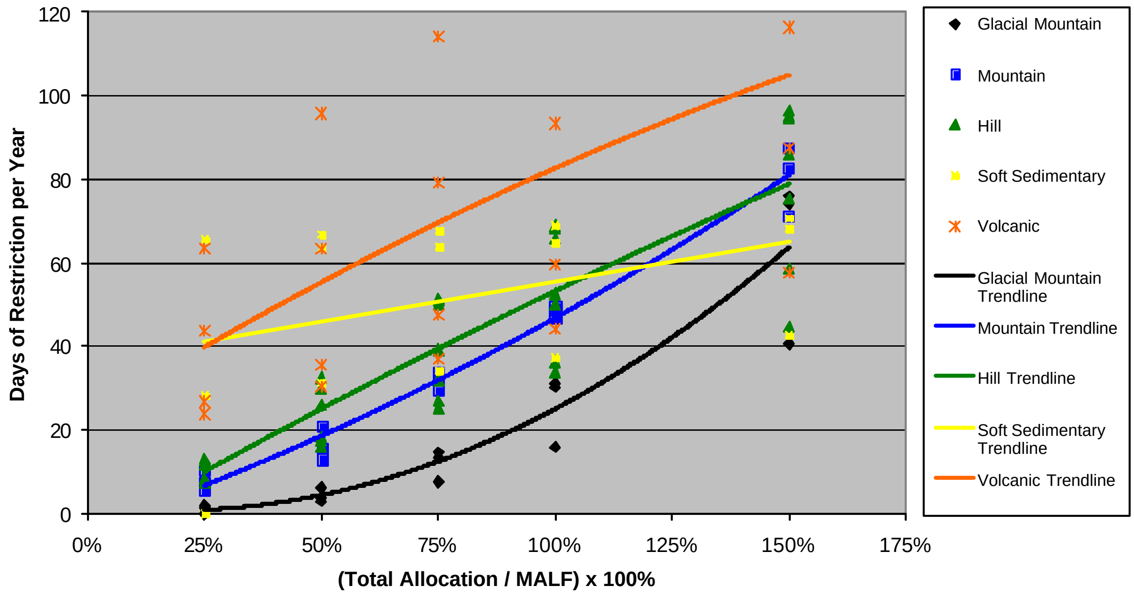

Figure 8: Days of restriction per year for all rivers organised by management unit.

The annual days of restriction analysis provides a preliminary indication of the Total Allocation that will meet the days of restriction criteria of 10%. The irrigation season used in the demand model is 34 weeks. An acceptable number of days of restriction is therefore in the order of 24 days per season. From the annual days of restriction analysis this occurs at a total allocation of approximately MALF for the Glacial Mountain management unit, 50% of MALF for the Mountain and Hill management units and at very low levels (less that 25% of MALF) for the Volcanic and Soft Sedimentary management units.

5.3 Timing of restrictions analysis

Using the levels of total allocation derived from the annual days of restriction analysis, we were able to examine the timing of restrictions through the year for each management unit. This analysis is the same as the annual days of restriction analysis but is carried out at a monthly time step and the data is shown below for a single level of total allocation. The analyses are shown on Figures 9 to 13 below.

The timing analysis shows the time of the year when abstraction is most restricted and is generally mid to late summer. The Glacial Mountain management unit has its most restricted period somewhat later than the other management units due to the sustained summer flows (see Figure 7). This pattern is less apparent than the seasonal analysis of flows shown in Figure 7 because the demand model assumes a reduction of demand in February and March when flows in the Glacial Mountain rivers are lowest. This highlights the point that the reliability of supply estimates is sensitive to the demand model.

The timing analysis also increases the resolution of the days of restriction analysis. The timing analysis shows that all management units are restricted, on average, approximately six days in the most restricted month. This is consistent with the days of restriction criteria of 20% for the most restricted month. The total allocation for each management unit derived from the annual days of restriction analysis therefore appears to also satisfy the criteria for the number of restricted days in the most restricted month.

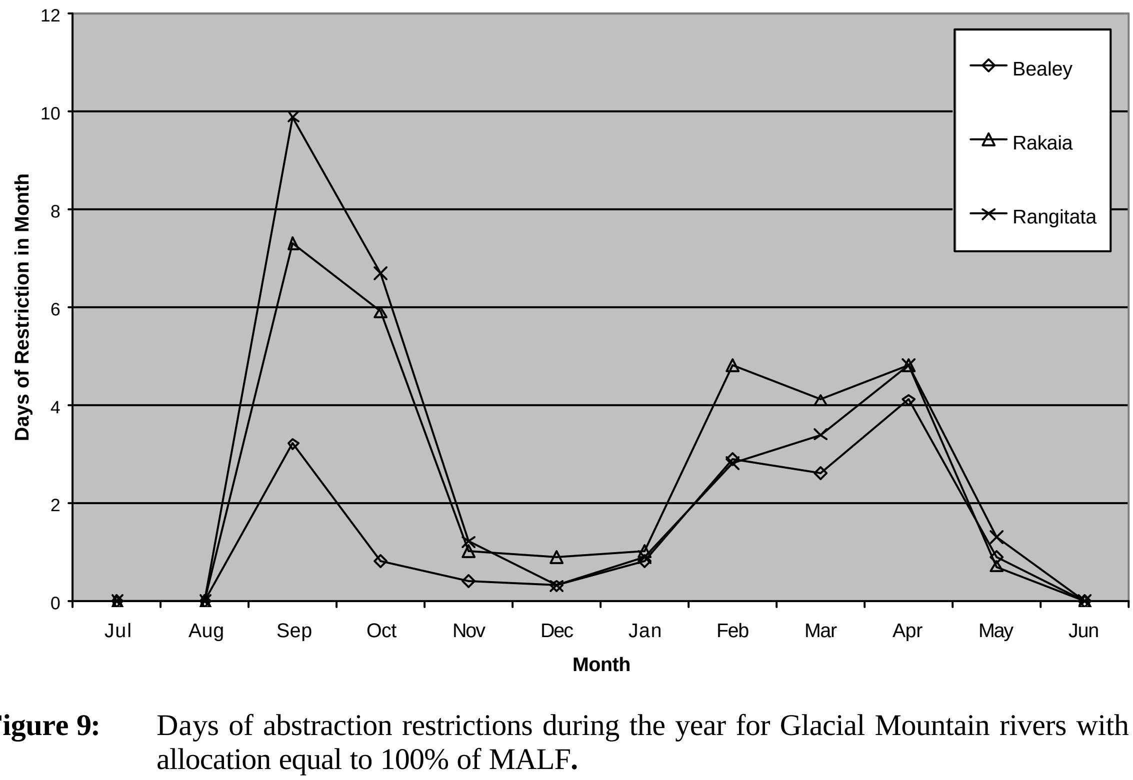

Figure 9: Days of abstraction restrictions during the year for Glacial Mountain rivers with total allocation equal to 100% of MALF**.**

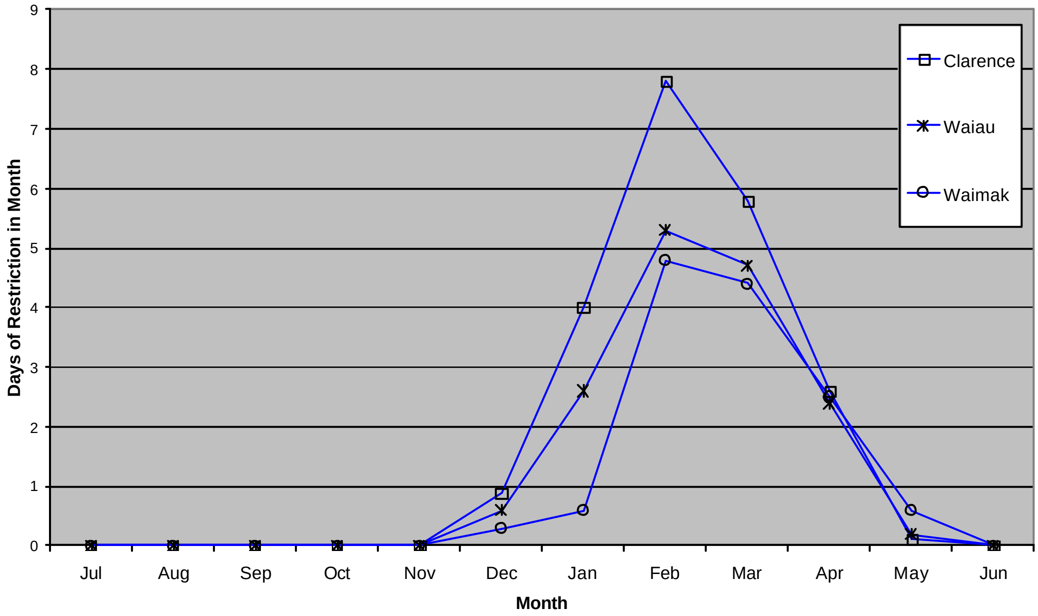

Figure 10: Days of abstraction restrictions during the year for Mountain Rivers with total allocation equal to 50% of MALF

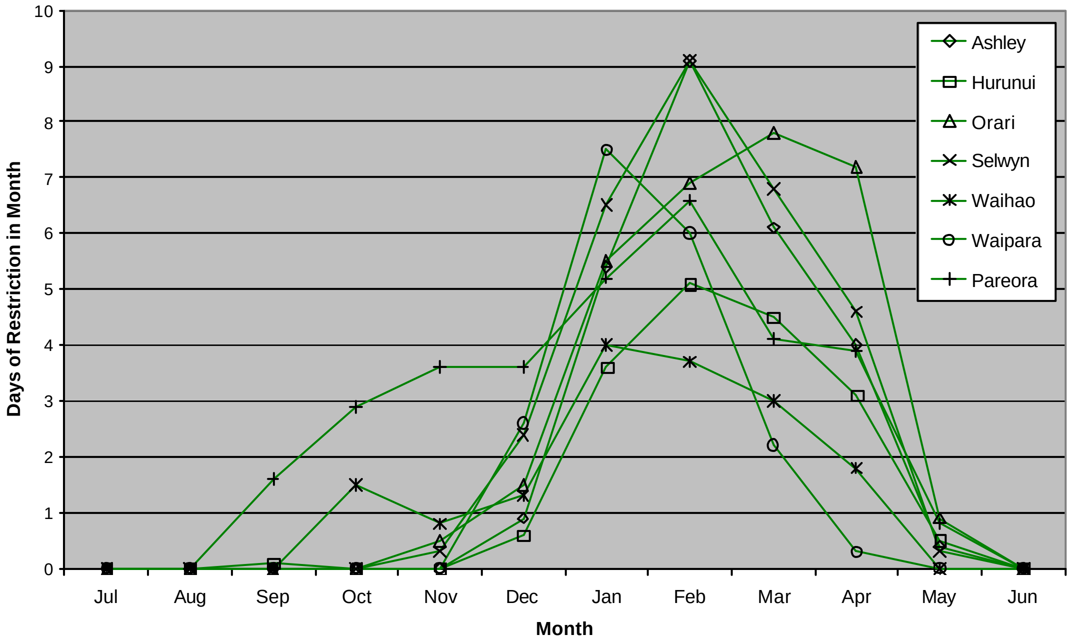

Figure 11: Days of abstraction restrictions during the year for Hill rivers with total allocation equal to 50% of MALF.

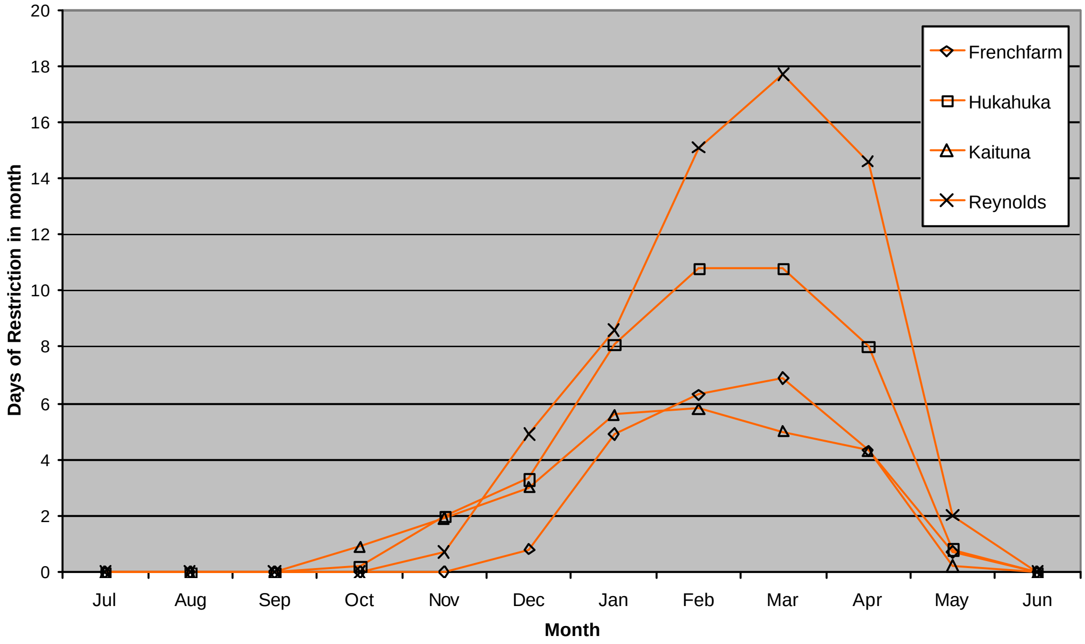

Figure 12: Days of abstraction restrictions during the year for Volcanic Rivers with total allocation equal to 25% of MALF.

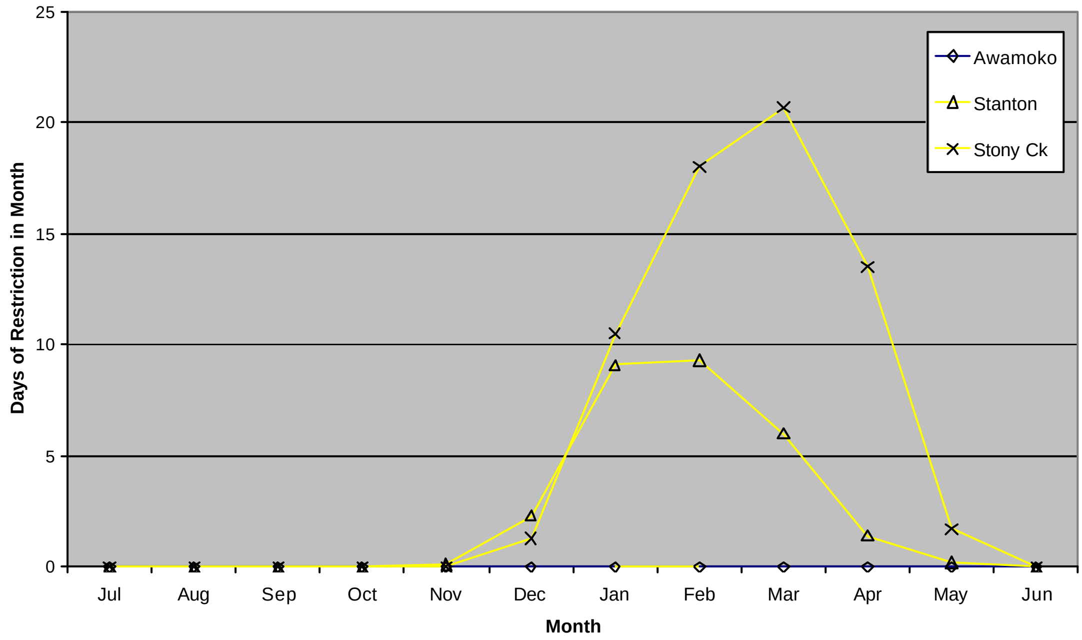

Figure 13: Days of abstraction restrictions during the year for Soft Sedimentary with total allocation equal to 25% of MALF.

5.4 Cumulative days of restriction analysis

A cumulative days of restriction analysis answers questions about whether the days of restriction occur separately or cumulatively (and therefore potentially less acceptably for irrigators). This analysis shows the probability (i.e. average number of events per year) of more than 7 and 20 days of restriction. The criteria assume that a single event of more than 7 days is acceptable on average once per year and an event of more than 20 days is acceptable only every 5 years. The results are presented in Figure 14 and 15 for all management units and a range of total allocation. Total allocation has again been scaled by dividing by MALF so that all sites can be shown on the same graph. Lines of best fit have been fitted to show the trends in the data.

The consecutive days of restriction analysis shows similar types of patterns to the other analyses. The Glacial Mountain management unit has the lowest probability of restricted periods followed by Mountain and Hill management units. The trend lines can be used to characterise the 'average' variation in probability of restriction with change in total allocation for the management units. These trendlines indicate that total allocations for Mountain Glacial, Mountain and Hill that meet the restriction criteria discussed above (Mountain Glacial of 100% of MALF, Mountain and Hill of 50% of MALF) also meet the 7 and 20 consecutive days of restriction criteria.

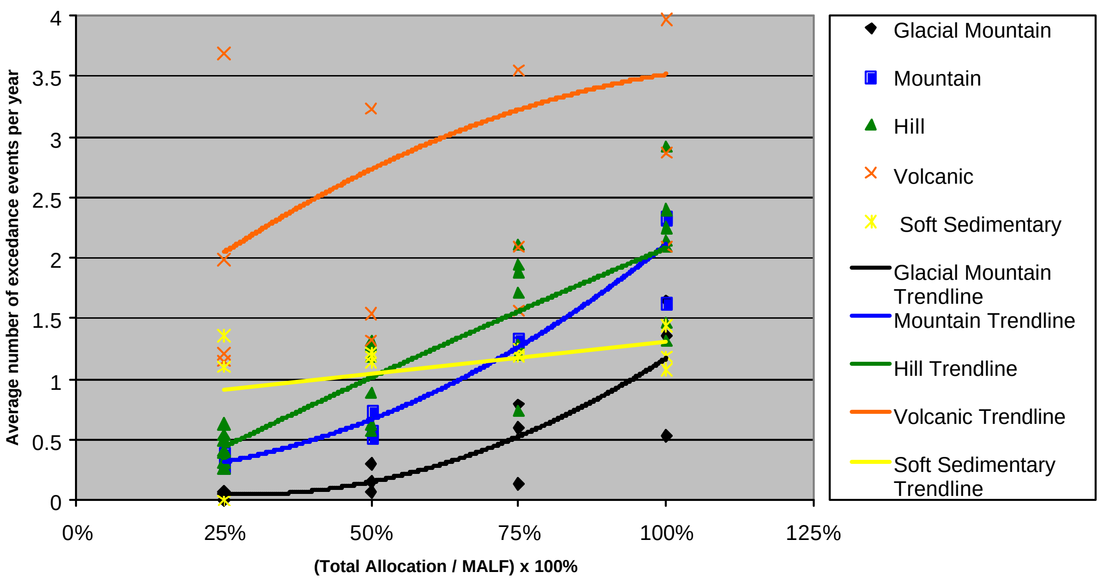

Figure 14: Consecutive days of restriction analysis for event durations of 7 days or more.

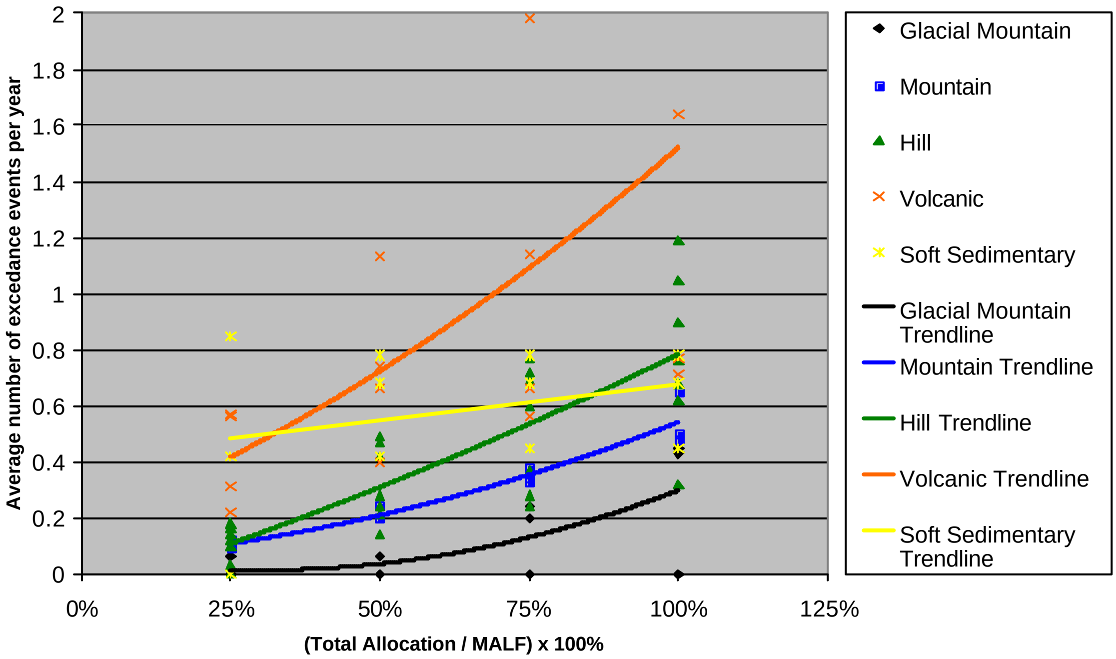

Figure 15: Consecutive days of restriction analysis for event durations of 20 days or more

The Volcanic and Soft Sedimentary management units fail to meet the 20 consecutive days of restriction criteria and Volcanic rivers also fail to meet the 7 consecutive days criteria. These management units are therefore subject to extended periods of low flow. There is an apparent reduction in duration of restriction with increasing total allocation seen for the Soft Sedimentary management unit. This is a consequence of increased allocation simply 'joining' restricted periods together so that two periods of restriction become one longer period. This illustrates the need to use a number of statistics to characterise the reliability of supply as single statistics may be misleading.

The scatter in the data points around the trend lines increases as the total allocation increases (i.e. further along the x-axis). The scatter is least for Glacial Mountain and Mountain management units indicating that these management units could be expected to behave relatively similarly. There is, however, considerable scatter in the data for the Hill, Volcanic and Soft Sedimentary management units. Even at the total allocations of 50% of MALF for Hills and 25 % MALF for Volcanic and Soft Sedimentary, there is considerable scatter in the data for these management units. This is the result of the variability in the environmental characteristics of the management units and the shortness of the flow records (particularly for the Volcanic and Soft Sedimentary data). More data and potentially, greater subdivision of the Hill class would reduce this scatter. Currently, however, there is insufficient flow data to better characterise the reliability of these management units Canterbury.

5.5 Effect of allocation on flow variability

Minimum flow settings protect in-stream values by controlling the intensity of flow reductions. Management regimes also need to consider whether flow reductions can significantly alter flow variability. Abstraction has the potential to affect two aspects of flow variability: the duration of low flow periods and reduction in the frequency and magnitude of high flows. These are important aspects of the flow regime for maintaining in-stream values. Extended periods of low flow can affect the ecosystem by allowing the accumulation of algae and plants (see MFE 1998, Volume B). Extended periods of low flow can also affect recreation and natural character by maintaining flows below a threshold for too long. The frequency and magnitude of food peaks is important because floods have a 'resetting' function for river ecosystems. Floods scour and flush sediments and plant material thereby maintaining the ecosystem 'health'. Floods can also remove vegetation including invasive plants from floodplain areas, thereby maintaining elements of recreation, natural character values and floodplain habitat.

In general, run of the river abstraction is assumed to have insignificant effects on flow variability. The number of flood events is very unlikely to be dramatically changed because floods are generally much larger than total allocation. Increases in the duration of low flow periods are affected by total allocation. As total allocation increases, the duration below any given flow threshold will also increase. If allocation is large, flows can be drawn down around the set minimum for long periods. We have undertaken two analyses to test the assumption that changes in flow variability arae insignificant for the general flow management regimes derived above.

There are no 'accepted' methods for determining acceptable levels of change in flow variability in rivers. The effect of total allocation on flow variability, however, can be analysed in a number of ways. In this analysis we have considered the effect of total allocation using two analyses. The first analysis considers the effect of total allocation on the number of flood events. The second analysis considers the effect of total allocation on the duration of low flows.

The flow statistic FRE3 is the number of times per year that flows exceed a flood flow threshold of three times the median flow. The value of FRE3 provides an index that allows a comparison of flood frequency between rivers and change in flood frequency for a particular river under a flow management regime. Large changes in the value of this index for a river would indicate a significant change in the flood frequency and this could be expected to affect values (MFE 1998). The difference in this statistic for natural and residual flows can therefore be used as an indicator of change in flow variability. We calculated[3] FRE3 for the Glacial Mountain and Mountain rivers for their suggested total allocations of 100% of MALF and 50% of MALF. The results are shown on Table 2 below.

Table 2: Comparison of FRE3 (calculated using the median of the natural flow record) for natural and residual flows in Glacial Mountain and Mountain rivers for the general flow management regimes.

River	Natural FRE3	Residual FRE3
Bealey	14.32	14.08
Rakaia	5.83	4.91
Rangitata	6.30	5.36
Clarence	6.76	6.37
Waiau	6.87	6.57
Waimakariri	5.95	5.54

The results in Table 2 show that there is an insignificant change in flood frequency under the general flow management regimes. The change in FRE3 is significantly less than the inter-annual variability in flood frequency. Effects on values, due to change in flood frequency under the flow management regimes, are therefore unlikely. The change in FRE3 for the other management units will be lower as total allocation as a proportion of MALF is lower than for the Glacial Mountain and Mountain rivers.

The final analysis considers whether the flow management regimes significantly affect the duration of low flows. The proportion of time a river is at or below any given flow is shown by a set of hydrological statistics called a flow duration curve. This analysis has developed flow duration curves for each management unit for the level of total allocation that meets the restriction criteria above (100% of MALF for the Glacial Mountain management unit, 50% of MALF for the Mountain and Hill management units and 25% of MALF for the Volcanic and Soft Sedimentary management units). Flow duration curves for the Glacial Mountain and Mountain management unit are shown on Figure 16 and 17. The graph shows the percentage of the time flows are lower than a given flow (expressed as a percentage of MALF). The results for the

[3] Arguably FRE3 for the residual flow should be calculated using three times the median flow for the residual flow record as the flood flow threshold. We calculated FRE3 for the residual flow using both three times the natural median flow and three times the residual median flow. There is a relatively large decrease in median flows for the residual flows because MALF is large compared to the median. This results in values of FRE3 being <u>higher</u> for the residual flow record than the natural flow record; a somewhat confusing outcome. In both cases, however, the residual flow FRE3 for each river is very similar to the natural FRE3.

other management units have been summarised on Table 4. Table 4 shows the increase in the proportion of the time that the flow is equal to or below MALF (i.e. the difference between the natural flow and the residual flow in the proportion of the time that the flow is equal to or below MALF).

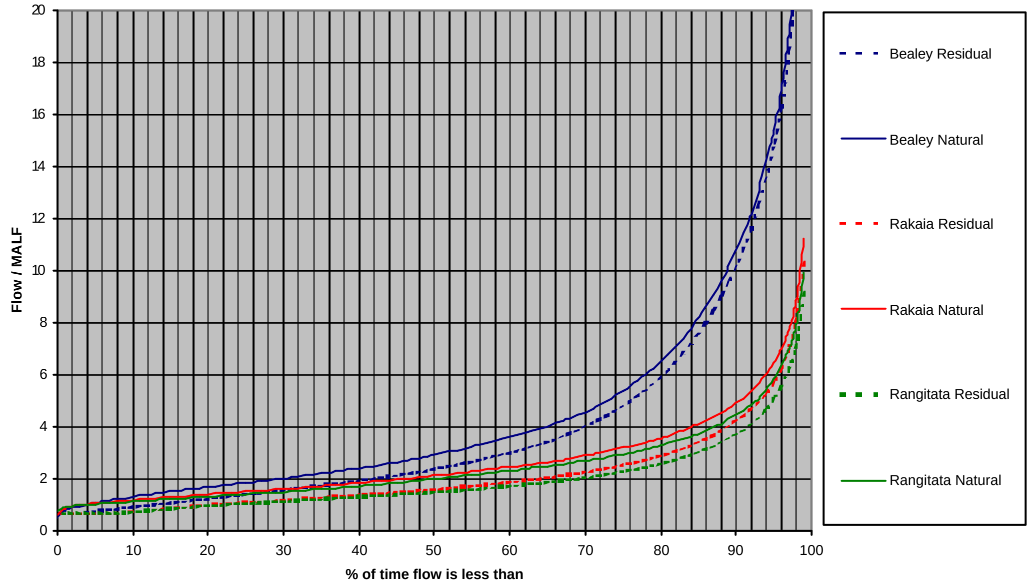

Figure 16: Change in flow duration for Glacial Mountain management unit

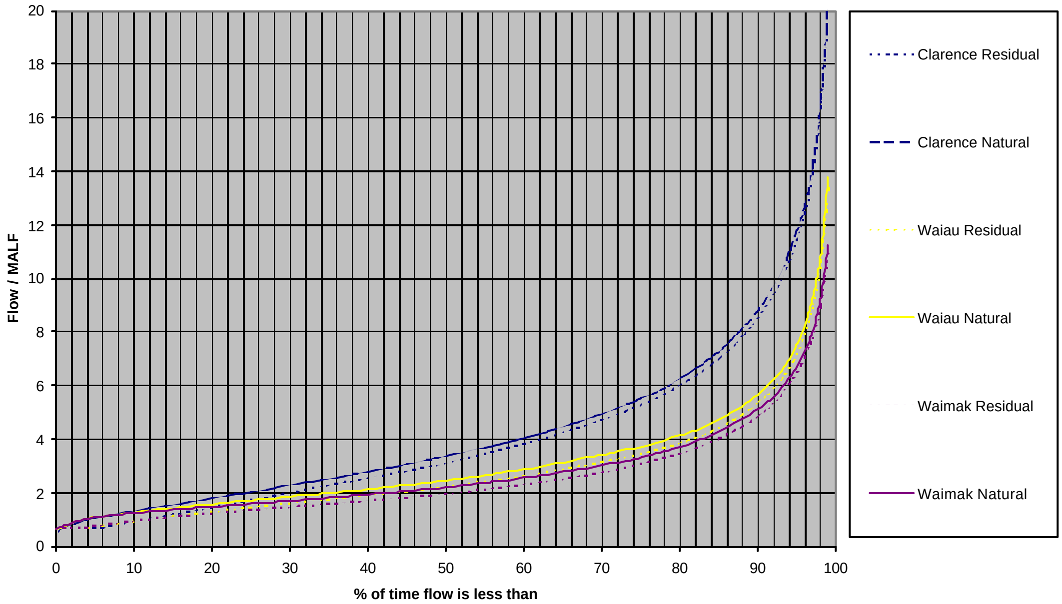

Figure 17: Change in flow duration for Mountain management unit

The results of the flow duration analysis indicate that, within a management unit, there is a consistent effect of a general management regime on flow duration curves. It is noted that the increase in time at or below MALF (or any other flow threshold) increases as allocation increases. Glacial Mountain rivers, therefore, have the greatest change in their flow duration curves because total allocation is highest in these management units. The 'acceptability' of the results of this analysis is not considered here. The results indicate that there is quite a significant increase in the duration of low flows for Glacial Mountain rivers. Because the Volcanic and Soft Sedimentary management units have minimum flows set and MALF there is in fact no change in the time at or below this threshold. The analysis demonstrates that the acceptability of changes in flow duration as a function of total allocation could be considered for each management unit at a regional level. If necessary, the total allocation provisions of the general flow management regimes could be set to maintain flow variability at acceptable levels.

5.6 Consequence of scaling minimum flow to MALF

The approach to developing a general flow management regime taken above has used 'environmentally conservative' approaches to setting minimum flows. In general, the same objectives can be met in larger rivers by setting minimum flows that retain proportionally less flow than smaller rivers. In this section we test the sensitivity of water availability to the choice of minimum flow. As discussed in Section 4.5.2, the minimum flow setting method used for the above analysis assumes that the same relationship between instream values and flow holds for all rivers regardless of size. Jowett (1993) found for a number of flow versus trout habitat relationships in the Wellington region, that 67% of MALF always retained at least $2/3^{rds}$ of the habitat. Retaining 67% of MALF is therefore an environmentally conservative minimum flow for retaining $2/3^{rds}$ of the trout habitat in the Hill management unit based on the objective of retaining two-thirds of what is available at MALF. Inspection of Jowett's (1993) results shows that on average, less than 67% of MALF will retain $2/3^{rds}$ of the habitat at MALF. The habitat of larger rivers in the Wellington region decreased less rapidly as flow starts to reduce below MALF. In general the retention of 50% of MALF for these larger rivers retains more than $2/3^{rds}$ of the trout habitat at MALF. The rules of thumb we use here may therefore be considered to be overly protective in large rivers.

The effect of river size on the flow required to meet an objective can be taken into account by deriving a regional relationship for rivers of a region (MFE 1998, Volume B). These regional IFIM methods set minimum flows based on objectives that retain a set amount of habitat. Habitat may be quantified in terms of some minimum amount of habitat provided the reduction is limited to (say) $2/3^{rds}$ of that available at MALF (see

Jowett 1993). We therefore used a regional minimum flow setting method derived for the Wellington Region by Jowett (1993) to investigate the effect of reducing the minimum flow in the larger rivers of the Hill management unit. The Wellington regional relationship retains a minimum amount of habitat provided this is not less than 2/3rds of the trout habitat available at MALF. Jowett's (1993) regional relationship for Wellington is :

Minimum flow (as a percentage of MALF) = 21.6 +214/(1+3.06 MALF) (Where MALF is expressed in m^3/s)

The effect of this equation is to retain a smaller proportion of MALF, and therefore river size, as MALF increases. Note that flow retained would never decrease below 21.6% of MALF (the constant in the above formulation). The minimum flows derived from this relationship for the larger Hill rivers (i.e. those for which the above relationship returns a minimum flow that is smaller than 2/3rds MALF) are shown on Table 3.

These minimum flows were used to carry out an analysis of days of restriction. The results are shown on Figure 16 below. Figure 16 also shows the results of the days of restriction analysis using 67% of MALF as the minimum flow.

Table 3: Comparison of minimum flows for Hill rivers set by two methods.

		Minimum flow (l/s)	
River	**Site**	**2/3 MALF (l/s)**	**Regional relationship (l/s)**
Ashley	Gorge	1369	1047
Orari	Gorge/Silverton	1877	1235
Hurunui	Mandamus	11444	4394

Figure 16 highlights two points. Firstly there is a significant difference in the days of restriction for the same site at different minimum flows. This indicates that restriction is sensitive to minimum flow as would be expected. Figure 16 also shows that water availability is relatively higher in larger rivers than smaller ones as larger rivers are relatively less sensitive to flow reductions.

Further subdividing the management units by river size could be used to group rivers whose minimum flows would be similar proportions of MALF. The same management objective would be applied across all size classes; however, minimum flows for management units based on large size classes would retain a relatively smaller proportion of flow. This further subdivision of the management unit would produce less restriction, or conversely, could increase allocation in larger rivers. The problem with using this further subdivision approach, however, is that there are insufficient flow records to apply the analysis and identify a consistent pattern of behaviour for a range of size-based management units. Even this study, which treated all size classes the same, was limited by data availability. At present it is not possible to develop a good set of reliability predictions for a range of size classes for any management unit because of insufficient data.

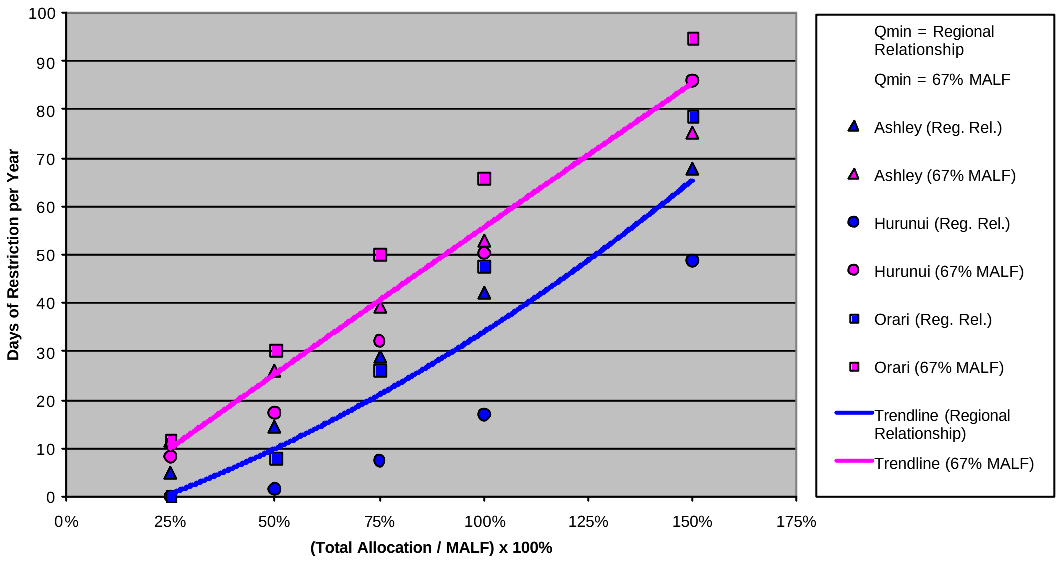

Figure 18: Days of restriction analysis for large Hill rivers showing the difference in reliability for minimum flows set by two methods.

The conclusion is that management needs to make a fundamental choice. The first option is to accept some uncertainty regarding the level of protection afforded to instream values in order to gain a clear appreciation of the effect of flow management on water reliability. The alternative is to set very consistent levels of protection for instream values at the expense of understanding the affect on out-of-stream use.

6 SUMMARY AND DISSCUSION

This study has investigated a set of general water management regimes that apply to different management units within a region. The objectives of this study were to;

- Determine whether significant differences in management regimes are appropriate among management units.

- Determine if general water management regimes result in consistent implications for water reliability and residual flow in rivers *within* a management unit.

- Use the approach to generate a series of management regime options that can be used in the policy development process.

Before the objectives of the study are discussed the assumptions and results are summarised.

6.1 Management regime options

The analyses carried out in order to answer these questions are complex because of the number of assumptions involved. In addition, many assumptions and decisions that have been made in the course of the analysis are essentially policy options. These options would require scrutiny by affected parties and a political decision making process, such as a regional plan, to ratify them. The study has chosen 'options' for the following decisions and proceeded in order to progress the analysis:

- Management objective including level of protection
- Minimum flow setting method
- Demand model
- Supply reliability criteria

The choice of these options results in consequences for both in-stream and out-of-stream values. The analysis is able to provide generalised information for each management unit including:

- Minimum flow
- Days of restriction per year
- Days of restriction in any month
- Probability of restriction events (cumulative days of restriction)
- Change in frequency freshes and duration of low flows

Because the choice of each option can change the results of the analysis, a range of options might be considered and the results presented as a set of possible management regimes. The regimes describe both the minimum flow and allocation and the consequence of the regime on out-of-stream users (supply reliability) and in-stream values (minimum flow and effect of allocation on frequency and duration of low flows). One option for each management unit is summarised on the Table 4 below. Table 5 looks at a single management unit (Hill) and develops a series of management regimes based on different objectives (and, therefore, different minimum flows) and different Total allocation (resulting in differences in reliability of supply).

Table 4: Summary of general flow management regimes and consequences for supply reliability and residual flows.

Management unit	Management objective	Level of protection	Minimum flow	Allocation	Days of restriction per season (average & range)	Days of restriction in most restricted month (average and range)	Number of events per year of greater than 7 days of restriction (average & range)	Number of events per year of greater than 20 days of restriction (average & range)	Increase in time flows are at or below MALF (average & range)
Glacial Mountain	Natural character/ recreation	Retain 9/10ths of depth at MALF	68% MALF	MALF	25.9 16.0 – 31.3	7.10 4.1 – 9.9	1.18 0.53 – 1.65	0.29 0.00 – 0.45	15.1% 8.8% – 18.8%
Mountain	Natural character/ recreation	Retain 9/10ths of depth at MALF	68% MALF	50% MALF	16.7 13.2 – 21.2	5.97 4.8 – 7.8	0.61 0.52 – 0.74	0.21 0.20 – 0.24	7.97% 7.2% - 8.4%
Hill	Brown Trout	Retain 2/3rds of habitat at MALF	67% MALF	50% MALF	24.4 16.1 – 32.3	7.03 4.0 – 9.1	1.02 0.57 – 1.32	0.32 0.14 – 0.49	1.93% 0.0% - 8.1%
Volcanic	General ecological value	DO criteria 6 mg/l	100% MALF	25% MALF	39.6 23.9 – 63.6	10.30 5.8 – 17.7	2.01 1.15 – 3.69	0.42 0.22 – 0.57	0.18% 0.0% - 0.4%
Soft Sedimentary	General ecological value	DO criteria 6 mg/l	100% MALF	25% MALF	31.4 0.0 – 65.7	10.00 0.0 – 20.7	0.82 0.00 – 1.36	0.42 0.00 – 0.85	0.0% 0.0% - 0.0%

Table 5 Five options for general flow management regimes and consequences for supply reliability for the Hill management unit

Management regime options	Management objective	Level of protection	Minimum flow	Allocation	Days of restriction per season (average & range)	Days of restriction in most restricted month (average and range)	Number of events per year of greater than 7 days of restriction (average & range)	Number of events per year of greater than 20 days of restriction (average & range)
1	Brown Trout	Retain 2/3rds of habitat at MALF	67% MALF	50% MALF	24.4 16.1 – 32.3	7.03 4.0 – 9.1	1.02 0.57 – 1.32	0.32 0.14 – 0.49
2	Natural character/ recreation	Retain 8/10ths of depth at MALF	44% MALF	50% MALF	8.5 6.1 – 13.0	3.4 2.2 – 5.6	0.33 0.28 – 0.42	0.08 0.00 – 0.16
3	Brown Trout	Retain all habitat at MALF	100% MALF	50% MALF	49.2 31.8 – 64.3	11.9 8.2 – 14.8	1.95 1.15 – 2.61	0.73 0.32 – 1.13
4	Brown Trout	Retain 2/3rds of habitat at MALF	67% MALF	100% MALF	53.6 33.9 – 68.7	12.9 9.2 – 16.9	2.07 1.32 – 2.90	0.78 0.32 – 1.19
5	Brown Trout	Retain 2/3rds of habitat at MALF	67% MALF	25% MALF	10.4 7.5 – 12.8	3.7 2.2 – 5.3	0.43 0.27 – 0.56	0.10 0.00 – 0.16

Table 5 presents five options for general management regimes. Option 1 is based on an objective that retains 2/3rds of habitat at MALF. Total allocation is managed to achieve the criteria set out in Section 4.8 (i.e. total allocation is 50% of MALF). Option 2 demonstrates a completely different management objective. The objective applies to natural character and/or recreation values. A nominal level of protection of retaining 8/10ths of the minimum passage depth at MALF is used. This results in lower minimum flows (44% of MALF). Option 2 sets total allocation at 50% of MALF. The lower minimum flow results in higher reliability that Option 1. Option 3 is similar to Option 1 but sets the level of protection to retain the entire brown trout habitat at MALF. The increase in minimum flow that results from this option reduces the reliably of supply compared to Option 1. Options 4 and 5 are based on the same management objective and level of protection as Option 1. The effect of increased total allocation is shown in differences in reliability of supply. Comparison of the results between Option 1 , 4 and 5 show that increasing total allocation (as a percentage of MALF) reduces reliability of supply.

6.2 Are significant differences in management regimes among management units appropriate?

Previous work (Snelder et al 2000) determined that the management units used to stratify the rivers of Canterbury (Glacial Mountain, Mountain, Hill, Volcanic and Soft Sedimentary) are significantly different with respect to the values they support. This study has also demonstrated that there are generalised differences in the natural flow regimes of the management units. These differences in flow regime are highlighted on Figure 7. In combination with a model of water demand (Figure 6), the management units differentiate rivers that are significantly different with respect to their water availability for out-of-stream use and therefore their value as water resources.

Using the criteria that we adopted, water availability is highest in the Glacial Mountain management unit. Total allocation of up to 100% of MALF can occur in these rivers (assuming the demand model) without exceeding the nominated supply reliability criteria. Mountain and Hill management units have the next highest water availability. Allocations of 50% of MALF can be made without exceeding the reliability criteria. The seasonality and reliability of Mountain and Hill rivers is similar and therefore from a water resource point of view these two management units appear similar. Aggregation of the two management units to form a single unit is not justifiable, however, because there are differences in values between the two management units. Minimum flows have, therefore, been set differently in each management unit. Water availability is lowest in Soft Sedimentary and Volcanic management units. These management units fail to meet the reliability criteria at an allocation as low as 25% of MALF.

The reasons for differences between management units in water availability is due to differences in the timing of the summer low flow periods compared to the timing of peak demand and differences in the minimum flow required to meet the management objective. In summary, the management units represent rivers that have significant differences with respect to water management and therefore provide a useful stratification of rivers for water allocation management.

6.3 Can management regimes be applied consistently within a management unit?

The study has established that management units can be used to broadly stratify rivers for water allocation management. The second question asks whether general flow management regimes can be developed for within each management unit. A generalised flow management regime would apply a consistent management objective to instream values and would apply a consistent set of reliability criteria for out-of-stream uses. To be useful, the water availability must also be consistent for all rivers in a management unit. Consistency across all these aspects of water management will allow a general framework for managing water allocation at the regional level, the implications of which can be understood. Such a framework also allows minimum flows and allocations to be set for rivers without detailed flow data, and for the consequence of this for reliability of supply to be predicted.

The application of a general flow management regime to a management unit is dependent on scaling minimum flows and allocation to account for differences in the size of rivers belonging to the management unit. We have scaled minimum flows and allocation by relating these to a flow statistic; MALF. We have then examined whether a consistent management regime results in a consistent pattern in reliability of supply for each management unit. The consistency of the patterns in reliability is summarised by the ranges in the various reliability statistics shown on Table 4.

In general, the analyses showed that a consistent pattern of reliability exists for Glacial Mountain, Mountain and Hill rivers. For all the analyses of reliability, the range in the calculated statistics was reasonably small. This means that for these management units, a generalised flow management regime leads to a reasonably predictable reliability of supply. The results for the Volcanic and Soft Sedimentary management units are less convincing. It is clear from the analysis that these rivers have, in general, lower water availability. The analysis does provide some general guidance on the acceptable size of the total allocation. Rivers within these management units, however, exhibit significant variability in their reliability statistics. The range in the days of restriction analysis (both annual and most restricted month) and the restriction duration analysis are very large. The consequences for water availability of applying a particular management regime, therefore, have fairly large uncertainty. The reason for this uncertainty is twofold. As discussed in Section 5.2, the hydrologically characteristics of the Volcanic management unit are understood to be extremely variable. In addition, there is a lack of suitable flow records, both in term of numbers of sites and record duration.

The analysis of variability showed that a generalised flow management regime will result in a reasonably consistent change in the flow duration curve within a management unit. There is some spread in the data (see Table 4), however, the implications of the application of the generalised management regime on flow duration can be explained with reasonable accuracy. This analysis has not considered the acceptability of the changes to flow duration. The changes in the flow duration curves need to be considered for specific values that could be affected, such as natural character and recreation. It is clear that larger total allocations will increase the time that flow is at or below any given threshold. The implications of a total allocation of 100% of MALF in Glacial Mountain rivers appear to be quite significant, increasing the time at or below MALF by approximately 15%. A total allocation of 50% of MALF in Mountain and Hill rivers results in a much lower increase in the time at MALF.

7 CONCLUSION

The study indicates that there are good reasons for managing allocation and minimum flows of a regions' rivers differently. The study has also shown that classification can be used to group rivers into management units for water allocation management. Significant differences in management regimes are appropriate among these management units.

In broad terms, general water management regimes result in consistent implications for both water reliability and residual flows in rivers *within* a management unit. It should be borne in mind that the exact implications are dependant on, and sensitive to, the details of the general management regimes. This analysis has made many assumptions that would need to be considered and ratified by a proper consultative process. The implications of generalised management regimes for Glacial Mountain, Mountain and Hill rivers are reasonably predictable from statistics derived for rivers belonging to this group. The implications of a generalised management regime for Volcanic and Soft Sedimentary rivers are less predictable. The results of the analysis for all rivers, however, provide managers with important insights into the effect of differences in total allocation. It is also clear that total allocation should be managed differently between management units. The analysis therefore provides a clear justification for a regional framework for water allocation that has different minimum flows and total allocation among management units.

The approach is strategic in order to provide a broad framework. The analysis compresses detail by aggregating data representing many rivers, treating all rivers within management units as being 'the same'. The implications of a general flow management regime within a management unit can be described in terms of a range in various supply reliability and residual flow statistics. A more accurate estimate of reliability for a specific river will often be possible by carrying out a specific, more detailed analysis. A more precise strategic analysis is conditional on increasing the number of management units and obtaining more hydrological data.

A larger number of management units would be needed to reduce differences between rivers and therefore decrease the range in the reliability and residual flow statistics. There are some benefits in doing this, particularly for minimum flow setting. This analysis has used environmentally conservative methods for setting minimum flows. These methods result in higher levels of protection in large rivers because, in general, these are less sensitive to change in flow than small rivers. More management units could achieve more 'optimal' identification of water availability while also ensuring a consistent level of protection for instream values. The downside of increasing the number of management units, however, would be increasing the complexity of the strategic framework. The second requirement for a more detailed analysis is the need for more hydrological data. We found that river flow data, particularly data that is either natural or that can be reliably naturalised, is extremely limited. While more management units can easily be defined using the REC, there is not sufficient data to represent the hydrological behaviour for these rivers. A potential solution to this is catchment-modelling techniques that provide synthetic flow records of natural flows.

The broad scale strategic analysis has kept complexity to a manageable level and used all available data. This was achieved by using conservative methods of minimum flow setting that ensure the values are sustained but that do not optimise water availability. In so doing, we are able to describe the effects on reliability of supply and residual flows with reasonable certainty. A framework that optimised for water availability would need to increase the number of management units by further subdividing the units we have used here by size (i.e. flow) classes. Because data is limited, however, the affect of the general flow management regime in each management unit would be difficult to understand.

These findings have important implications for any regional plan that is based on this strategic overview. Firstly, the flow management regime provisions should allow for some discretion to allow new information or more detailed analysis to make more optimal use of the resource. It is suggested that the overarching objectives for instream values and the reliability of supply criteria would remain essentially 'set'. The discretion would involve the ability to alter the minimum flow and/or total allocation where it could be shown that the objectives and reliability criteria would still be met.

This approach would allow the detailed management of a particularly important river resource that would be subsumed under provisions of the strategic framework.

The findings also point to significant data ‘gaps’. There are management units with no suitable flow records. The regional planning process could consider if these management units also coincide with catchments with high water demand and provide a structure and justification for future flow monitoring. There are also large numbers of sites that are affected by abstraction but for which no water use data is available. These records cannot, therefore, be reliably naturalised. The plan process could consider whether water use records could become a useful adjunct to existing flow monitoring.

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