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How To Use Volume B

This Volume B of the *Flow guidelines for Instream Values* provides technical and background information. It is designed to be read in conjunction with Volume A and can be likened to a reference document.

In this volume there is detailed discussion on:

- Hydrology.
- Hydraulics.
- Stream ecology.

There is also detailed discussion on how changes to flow regimes affect:

- Ecological values.
- Maori values.
- Recreational values.
- Landscape values.

There is also a description of the technical methods available for determining flow regime requirements.

Important Note

Because Volume B is essentially a reference document, it is best accessed through the relevant section in Volume A. Each section in Volume A directs the reader to the appropriate section(s) in Volume B.

1. Hydrology

1.1 Measuring flow in rivers

Flow data for rivers is gathered by continuously measuring water levels. Information from water level recorders is stored at regular time intervals (15 minutes), either on paper or electronically. This information is transferred to central archives held by the National Institute of Water and Atmospheric Research Ltd (NIWA) or regional councils.

Water level information is converted to flow rate with a stage-discharge relationship also known as a rating curve. Stage-discharge relationships are established by simultaneously measuring flow rate and water level for a range of flows. A continuous relationship between water level and flow rate is derived by drawing a line through these points on a plot of stage versus discharge.

Stage-discharge relationships can change if channel geometry changes. Floods in channels with unstable beds can change rating frequently, and stage-discharge relationships should be updated frequently to maintain the value of the data collected. Stage-discharge relationships are stored as time-dependent data as part of water level records. In this way there is always an appropriate stage-discharge relationship that can be applied to periods of water level record. This water level record with an applied stage-discharge relationship is referred to as a “flow record”.

1.2 Flow statistics

Hydrologists analyse time series of flow data to extract statistics which express characteristics of the flow regime. These analyses can be separated into overall flow statistics which express the whole flow regime, and low flow and flood flow statistics which consider the high and low extremes of the flow regime.

1.2.1 Overall flow statistics

Overall flow statistics consider the whole flow record.

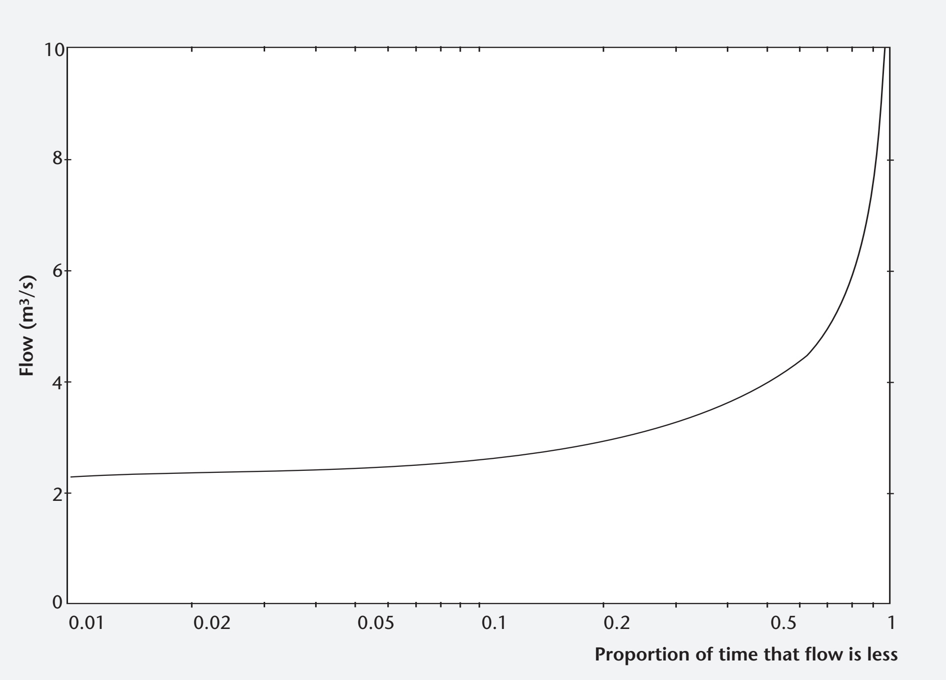
1.2.1.1 Yield and specific yield

The yield is the total volume of flow over a set period. It is calculated by integrating the area under a flow hydrograph. It is most usefully expressed as specific discharge, which is the average discharge per unit area of catchment ($l/s/km^2$).

1.2.1.2 Flow duration curve

A useful picture of the flow record can be provided by the flow duration curve. This curve shows the distribution of flow rates by comparing flow with the proportion of time that this flow is less. Rivers with very variable flow regimes will show a steep line on a flow duration curve, indicating a wide range. Rivers with stable flow regimes will have flatter lines on the flow duration curve.

Fig 1: Example of a flow duration curve for the Tahunaatara Stream in the Waikato (low relief stream with permeable soils)

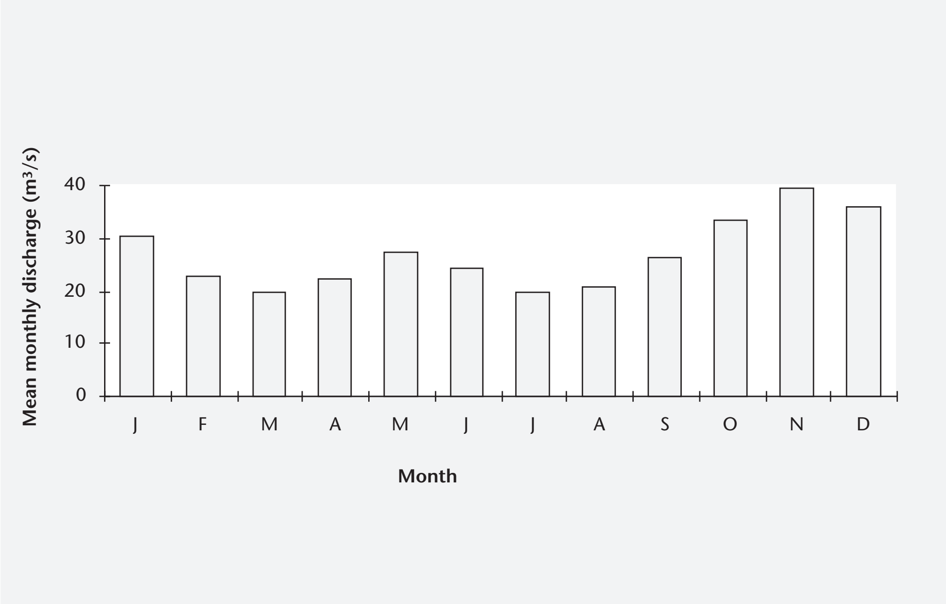


1.2.1.3 Monthly flow histograms

Another overall flow statistic is the monthly flow histogram. This shows average flows for each month based on the flow record. This type of analysis shows the seasonal variability of the flow regime. The extremes of the range of low and high flows are not shown in this type of analysis as they are in the flow duration curve.

Fig 2: Monthly flow histogram for the Gowan River

The Gowan River drains Lake Rotoroa in the headwaters of the Buller River catchment in the south of the Tasman region.



1.2.1.4 Mean flow and median flow

Aspects of the flow regime can be represented by single value flow statistics, often called flow variables. Commonly used flow statistics are the mean flow (MF), which is the total flow volume divided by the duration of the record, and median flow (Q50), which is the flow which is exceeded 50 percent of the time. These values represent average flow conditions. Flow variability can be measured by a skewness coefficient (SK), such as the MF divided by Q50, which expresses the degree to which the mean is affected by extreme values.

1.2.1.5 Coefficient of variation

The coefficient of variation (CV) is the standard deviation of the daily mean values divided by the MF and is a standardised measure of the spreading (variability) of the data. The coefficient of variation has been used in New Zealand studies (e.g. Jowett and Duncan, 1990) and although it is not always useful explaining observed differences in morphological and biological processes (Biggs et al., 1990), it is a measure of the variability of the flow regime. In general CVs are low (less than 1) in rivers with little flow variability and are large (greater than 3) in rivers where rivers have relatively long periods of low flow and then intermittent large floods.

1.2.1.6 Base flow index

Another flow variable which indicates overall variability is the base flow index (BFI). This is the volume of base flow in the record divided by the total volume of the record. Flow regimes which have many floods and low base flows are highly variable and have low BFI values. The opposite applies to stable flow regimes.

1.2.1.7 FRE_3

Biologists are interested in the frequency that river biota are subject to disturbances generated by flood flows. A method of describing this frequency is to calculate the average number of times per year that the flow exceeds some multiple of the median flow. Recent research (Clausen and Biggs 1996, a, b) has identified that the average annual frequency at which flows exceed three times the median (FRE_3) is the most useful flow statistic for classifying rivers according to the habitat for benthic biota (periphyton and invertebrates). The statistic FRE_3 is derived by calculating three times the median flow, counting the number of occasions that this was exceeded in the flow record and dividing this number by the number of years of record.

The value of FRE_3 is shown for sample flow regimes on Table 1 below.

Table 1 FRE_3 for sample flow regimes

Flow Regime Type	Sample flow regimes	FRE_3
Lake or spring	Kaituna at Lake Rotoiti Outlet	0
Low relief country (1)	Rangitaiki at Murupara	0.4
Low relief country (2)	Waihopai at Kennington	12
Inland hill country	Motu at Houpoto	22
Non-glacial mountain	Waimakariri at Old Highway Bridge	10
Glacial mountain	Rakaia at Gorge	9

Fig 3: Hydrographs showing FRE_3 for sample flow regimes

The horizontal line through the hydrograph is three times the median flow. The average number of times the hydrograph exceeds this value in a year is FRE_3 (flows are in m^3s^{-1}).

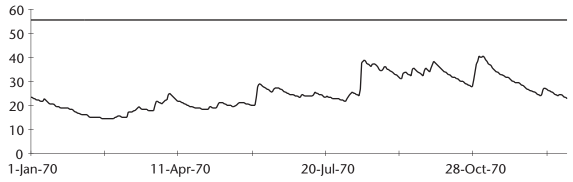
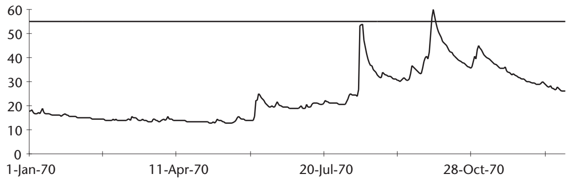
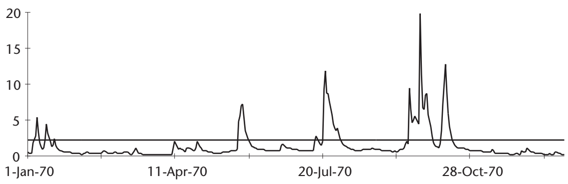
Flow Regime Type	Sample flow regimes
Lake or spring	 **Figure 3(a) Kaituna River**
Low relief country (1)	 **Figure 3(b) Rangitaiki River**
Low relief country (2)	 **Figure 3(c) Waihopai River**

Fig 3: Hydrographs showing FRE$_3$ for sample flow regimes (continued)

The horizontal line through the hydrograph is three times the median flow.
The average number of times the hydrograph exceeds this value in a year is FRE$_3$ (flows are in m^3s^{-1}).

<table>
<tr><th>Flow Regime Type</th><th>Sample flow regimes</th></tr>
<tr><td>

Inland hill country

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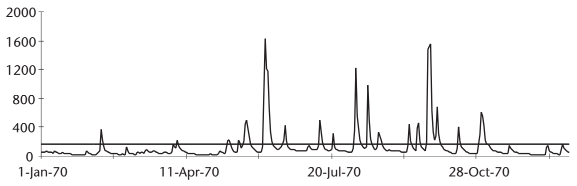

Figure 3(d) Motu River

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Non-glacial mountain

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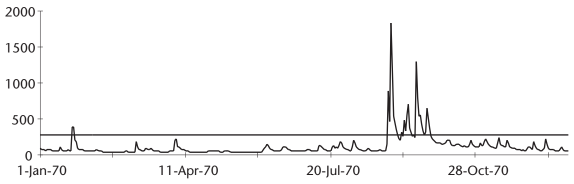

Figure 3(e) Waimakariri River

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Glacial mountain

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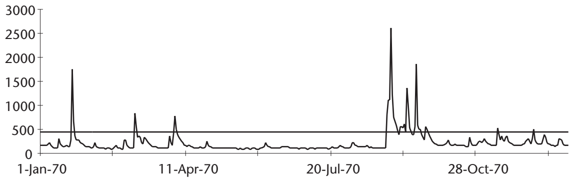

Figure 3(f) Rakaia River

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1.2.2 Low flow statistics

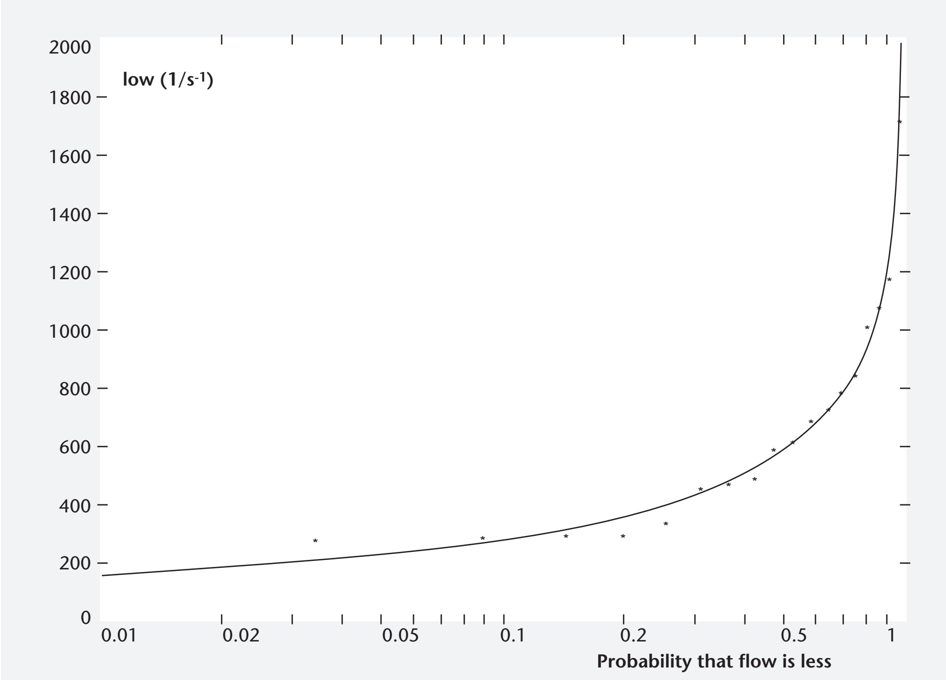
The frequency and magnitude of low flow events are key parameters of a river. Low flows can be critical points in the flow regime for biological communities and for resource users. An understanding of their occurrence, frequency and magnitude is therefore vital when considering flow regime requirements.

1.2.2.1 Annual minimum flow distribution

Low flow statistics can be presented as an annual minimum flow distribution. These analyses give the frequency of flows less than a given magnitude occurring for standard durations, usually 1 day, 7 days and 28 days. From these the probability of flows falling below a given value for these durations in any one year can be calculated. On average in New Zealand the instantaneous minimum flow is approximately 90 percent of the 1-day low flow, 80 percent of the 7-day low flow and 70 percent of the 28-day low flow. Figure 4 below shows a typical low flow frequency analysis.

Fig 4: 28-day low flow frequency analysis for the Hoteo River in the Auckland region

The probability in any year, that the flow is less than a value shown on the vertical axis for 28 days or more is shown on the horizontal axis. For example the probability of flows less than 200 ls^{-1} for 28 days in any year is 0.03 (3%).



1.2.2.2 Streamflow drought analysis

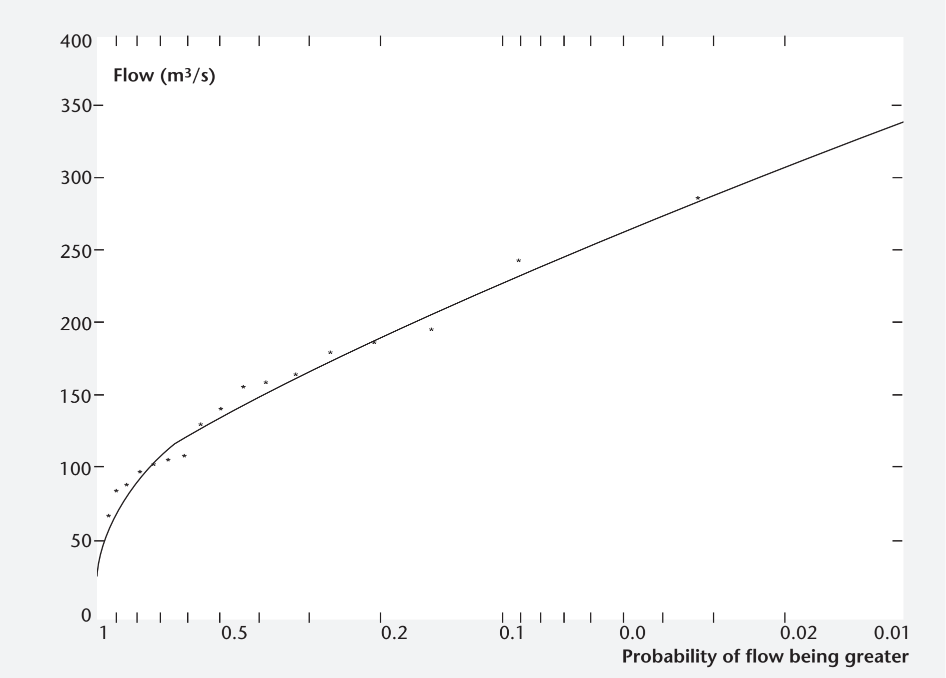
Annual minimum flow distributions do not provide a full indication of the deficit in volume that occurs when flows descend below a minimum threshold value. Streamflow drought analysis considers this deficit volume by calculating the probability of volume deficit below a given flow rate. Streamflow drought analysis is therefore useful for water resource users who may be required to stop abstraction below a certain flow.

1.2.2.3 Flood flow statistics

Flood flows can be referenced by their peak flow, the volume of runoff, and the time to peak which is the time from the beginning of the rising limb of the hydrograph to the peak flow. For engineering purposes the most commonly used statistic is the annual exceedance probability (AEP), which is the probability of a flow being equalled or exceeded in any year and is generally expressed as a percentage. AEP is the reciprocal of the return period, with a 50-year return period flood being a flow that is equalled or exceeded, on average, once in 50 years. This corresponds with a 2 percent AEP.

Fig 5: Flood flow frequency analysis for the Hoteo River in the Auckland region

The probability in any year, that a flood will equal or exceed a value shown on the vertical axis for is shown on the horizontal axis. For example the probability of a flood flow greater than 250 m^3s^{-1} in any year is 0.04 (4% AEP).



1.3 Availability of flow data

New Zealand has an extensive network of river flow recording sites dating from 1906. Time-series data of flow were recorded for more than 200 sites by NIWA and more than 100 sites by regional councils in New Zealand in 1995. There are a large number of closed flow recording stations for which useful records are available. Flow records are stored on a national archive administered by NIWA and on regional council archives. Some local authorities also collect data at sites and administer their own records. Existing and closed flow recording sites with more than five years of records (Walter, 1994) are shown in Appendix 1 of this document (Volume B).

1.4 Estimates of low and flood flow in catchments without flow records

Many catchments which are significant water resources do not have flow records. Estimates of low flows and flood flows for these catchments can be made by:

- Synthesis of flow records
- Regional methods
- Comparison with records in a catchment with similar source of flow (possibly relating an established flow record to flows in a catchment using concurrent gauging).

1.4.1 Concurrent gauging

Perhaps the most useful method of deriving flow records and statistics for catchments without flow records is the method of concurrent gauging. Hydrological data from catchments with flow records can be extended to other catchments within the same hydrological region. This is accomplished by carrying out a series of concurrent gaugings on the catchment without a flow record and using these to establish a relationship with flow in the gauged catchment. This relationship can then be used to produce either a flow record or flow statistics for the ungauged catchment.

Using this method requires some forward planning. At least five and preferably seven or more concurrent gaugings are required to establish a relationship over a range of flows. If these gaugings are carried out over a period from late winter to the summer low flow period, a relationship can be established in less than six months. A useful description of this method is described in Chandler (1969). Applications of the method are discussed in Waugh (1970), Grant (1971), Harrison (1988), and Clausen et al. (1997).

1.4.2 Synthesising flow data

Some catchments have very short periods of record which may not be sufficient to make statistical estimates from. Generally a flow recording site will be at a strategic location in the catchment with respect to water resource use, but often information is needed for a location in the gauged catchment which is remote from the recorder site. In these situations flow records can be synthesised.

Short records can be “extended” by comparing flows to flows at a nearby site for which climatic and geological conditions are similar, resulting in similar flow regimes. Comparison of the short period of record can be used to derive a relationship from which the short record can be extended by applying the derived relationship to the longer record.

In some situations a long period of rainfall record is available for a catchment with or without a period of water level record. Mathematical models run on computers can convert rainfall to flow. This is called rainfall-runoff modelling. If some flow data are available, this can be used to calibrate the model and the rainfall record can then be used to extend the flow record to the same length as the rainfall record. This can provide a flow record from which more certain statistical estimates can be made. Where there is no flow record available, model parameters can be derived from nearby catchments with the same climatic and geological conditions. The rainfall record can then be used to synthesise a flow record.

1.4.3 Regional flood flow estimation

A regression relationship for the mean annual maximum flood flow Q has been derived based on catchment area (A) from 343 catchments with an extended flow record in New Zealand (McKerchar and Pearson, 1990). Using this regression, maps with the value of a form of specific discharge $Q/A^{0.8}$ have been plotted for the catchments and in which smooth contours could be drawn. The contours generally reflect the pattern of annual rainfall and rainfall intensity but low values occur where geology has a significant effect on flood flows, such as in the absorbent volcanic ash soils of the central North Island. It is possible to estimate mean annual flood flows for catchments with no flow record by using estimates of the form of specific discharge read off the contour map. Flood flows of other return periods and the statistical certainty of the flood flow estimates can also be derived

1.4.4 Regional low flow estimation

Regional minimum flow frequency analysis has also been carried out for New Zealand in a similar manner (Pearson, 1995). The log of the specific mean annual minimum 7-day low flow (Q) has been plotted and contoured for the country using data from 500 catchments (see Figure 6). The contours can be used to estimate mean annual minimum 7-day low flow for catchments without flow data. An earlier method used regression equations for low flows based on catchment area, annual rainfall and land resource variables (Hutchinson, 1990).

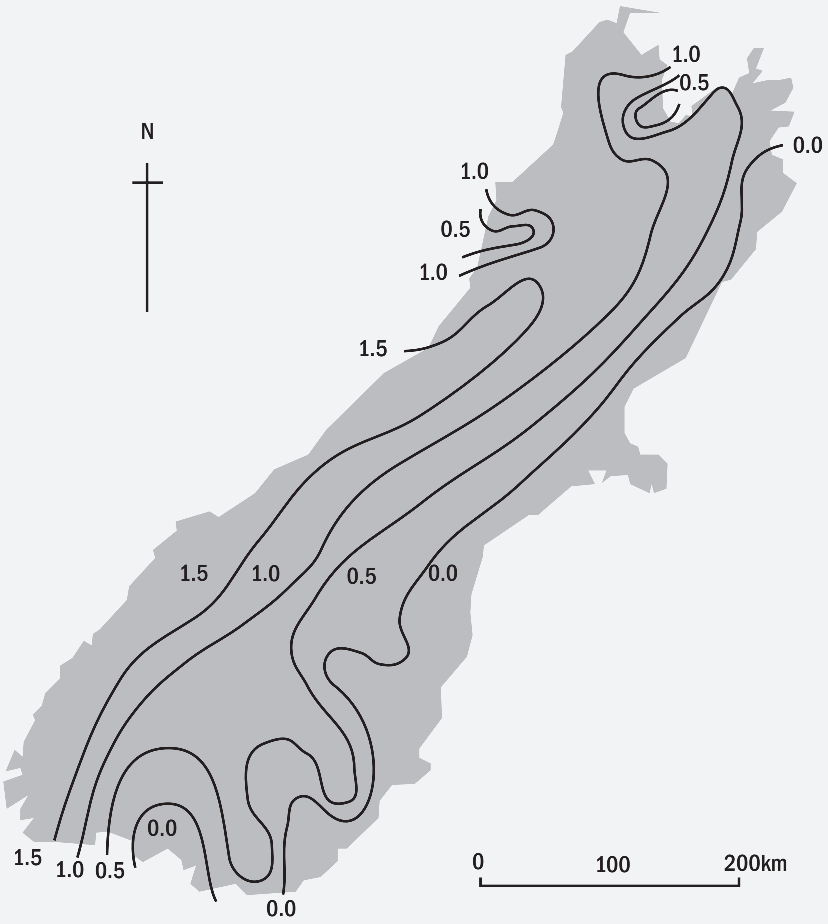
The contour maps of flood flow and low flow are very similar, reflecting the geological and climate variables which produce flow regimes. Regional methods for estimation of streamflow drought have also been developed for some parts of New Zealand (Clausen and Pearson, 1995).

Fig 6: Low flow contour maps

The maps show the contour lines $\bar{q}$, where

$\bar{q}$ = *log(QA / Catchment Area)*
and QA is the specific mean annual minimal 7-day flow (ls^{-1}).
catchment area is in km^2

No method yet exists for calculating low flows of other exceedance intervals. Initial research (Pearson, 1995) indicated that factors to convert MALF to other exceedances would be variable depending on the regional variables of climate and geology that affect low flows. These factors could be determined for different regions and would be a useful area of future research for resource managers.



Sample Calculation:

Take for example, a site with a catchment area of 10 km^2 at Hokitika in the South Island. From the contour map $\bar{q}$ is 1.5. From the relationship $\bar{q}$ = *log(QA / Catchment Area)*

The mean annual 7-day low flow is therefore:

QA = $10^{(1.5)}$ *l/s/km*^{2} x 10 *km*^{2}
= 316 *l/s*

1.5 References

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2. River Hydraulics and Morphology

2.1 Hydraulic conditions

For a particular cross-section, the hydraulic conditions (width, depth and velocity) are dependent on the:

- channel hydraulic roughness
- channel slope
- channel morphology comprising slope and channel geometry.

2.1.1 Channel hydraulic roughness

Flow can be described as uniform or non-uniform. Uniform flow conditions are those where the channel cross-section and velocity remain constant along a reach. This condition occurs when the friction of the channel and the slope are in equilibrium. The Manning equation predicts mean velocity of flow in a channel where uniform flow conditions apply and can also be applied as a reasonable approximation in non-uniform flow:

$$V = (1/n)\, R^{2/3}\, S^{1/2}$$

where S is the slope of the channel, n is Manning's roughness coefficient, and R is hydraulic radius which is equal to the wetted perimeter of the channel (P) divided by the channel area (A). In wide shallow channels (i.e. most New Zealand rivers and streams), R is approximately equal to the mean depth.

The flow rate (Q) is the product of mean velocity and channel area. It can be seen from the Manning equation that changes in flow can result in complex non-linear changes in depth, width and velocity.

In practice Manning's n must be measured or estimated (Hicks and Mason 1991). In relatively regular uniform channels, it is mainly determined by the flow resistance of the bed. Higher values of Manning's n are often used to approximate the total flow resistance of irregular channels, which may also be heavily vegetated.

A constriction in a channel - a narrow cross-section or one with a higher bed level than adjacent cross-sections as at a riffle - may act as a control, affecting water levels upstream. A backwater analysis based on Manning's formula must be applied to determine the water level and velocity just upstream of such a control.

Manning's n varies considerably from river to river. At low flows it varies from 0.01 to 0.25 depending on the type of river.

2.1.2 Channel slope

Most rivers exhibit a downstream decrease in gradient along their length as their flow is augmented by inflow from tributaries. This produces a concave longitudinal profile. Rivers with no tributaries, such as many on the Canterbury Plains, can have a more or less constant gradient.

These observations are generalisations, and a number of geological factors can cause variations. Channel slope adjusts to variations in rates of sediment supply and removal (Richards, 1982). This can be a factor to consider immediately downstream of dams that intercept sediment, or in rivers where a lot of gravel is extracted for the construction industry. However, in most other situations the processes are so slow that the channel slope at any particular location may be taken as unchanging.

2.2 Channel morphology (plan form and cross-section geometry)

Channel morphology refers to the three-dimensional shape or form of the river channel (cross-section geometry and plan geometry), including those bedforms (formations of sediment on the channel bed) which are linked in size with the channel width. River channels can be self-formed and self adjusting, but most are controlled to some extent by factors such as the valley topography, vegetation or stopbanks (Richards, 1982). The channel morphology and changes in morphology (such as sideways shifts in channel position across the valley) are responses to sediment erosion and deposition processes, which are in turn dictated by the flow regime, the channel slope, and the nature of the bed and bank material. In general it is flood flows rather than base flows that are important in these channel forming processes.

In these guidelines, consideration of channel shape is restricted to the active channel, which is the channel that carries the moderate, channel-forming flood discharges. In doing so, they exclude any floodplain that takes water that spills from the active channel in extreme floods. Such floodplains typically have terrestrial vegetation and may be regarded as land areas that are occasionally inundated.

Because the hydraulic conditions that are important for instream values are generally associated with base flows and low flows rather than flood flows, the channel form revealed at base flows is discussed in these guidelines. In these conditions higher areas of bed (i.e. bars of bed sediment) may be left dry, and the remaining channels often form a series of pools and riffles. Riffles are shallow swift-flowing areas with a broken water surface, and pools are deeper slow-flowing areas often containing finer bed material.

These guidelines use a categorisation of channel types. This section provides a background discussion of channel type.

2.2.1 Self-formed channel

Self-formed channels are those whose banks are formed of the river's own alluvium and where the lateral extent of the channel is not confined. In these channels important features of river mechanics govern the channel form.

The width-to-depth ratio of the stable channel form increases (from a minimum of about 10) with increasing discharge, increasing slope, or decreasing sediment size.

Due to instability, the beds of all but the narrowest river channels are transformed from a uniform cross-section to give rise to alternate bars. These bars are gravel deposits positioned against both banks in a staggered manner. They can also exist independently of meanders, and are sometimes found in the near-straight reaches of meanders. Another instability effect is bank erosion, which alters the plan form of the river (possibly in conjunction with the alternate bar process) giving rise to meanders.

These processes result in three basic types of self-formed channel: straight and meandering (both single-thread forms), and braided. These three channel types form a continuum, and there are a number of transitional forms. A number of more complicated classification systems have been suggested. The situation is complicated by flow variability. For example, a normally meandering river may adopt a braided form in response to a sustained large flood.

The transitions between these forms have not been precisely defined, but there is a clear progression from straight to meandering to braided, associated with: increasing slope, increasing discharge, and decreasing sediment size. All channel types may be represented at different points in a river catchment.

2.2.2 Straight single-thread self-formed channels

Straight self-formed channels have material that is barely mobilised by floods. They therefore occur only in flat terrain, and are rare in New Zealand except close to river mouths. Compared to meandering and braided channels, they have a low width-to-depth ratio, and therefore often have navigable water depths.

These channels are generally substantially uniform in cross-section along their lengths, without significant bars. In low flows, velocities and channel width are not substantially less than for higher flows, but depths are reduced approximately in proportion to the flow. The near-uniform channel generally ensures that the pool-riffle sequence found in other channel forms is not present, and variations in aquatic environment in space and over time are slight.

2.2.3 Meandering channels

The plan form of meandering channels is single thread with the distinctive regular sinuous twisting of the channel across the river valley.

The most commonly used measure of this phenomena is the sinuosity index (SI). This is the ratio of the channel length measured along the deepest part of the channel (the thalweg) and distance measured in a straight line down the valley:

$$\text{SI} = \frac{\text{Channel distance (along thalweg)}}{\text{Valley distance}}$$

Meandering is an instability effect associated with the interactions between water flow and the erosion and transport of sediment. The driving action of this instability are high velocities and secondary currents (spiral flow) at the outside of meander bends. These actions erode the outside bank and carry the eroded material away.

If not constrained, the meanders naturally migrate downstream, and also become more pronounced with time. Highly meandering channels can be found associated with low bed slopes, where they grow until a cut-off occurs, leaving a meander loop as an ox-bow lake. In conditions closer to the transition to braiding, the meanders are less pronounced, but the sediment transport processes are more vigorous, resulting in quicker downstream migration of the meanders.

A typical meandering channel has a U-shaped cross-section in the near-straight part of the meanders. Around the meander bends the channel is triangular in cross-section, with undercutting of the outside bank.

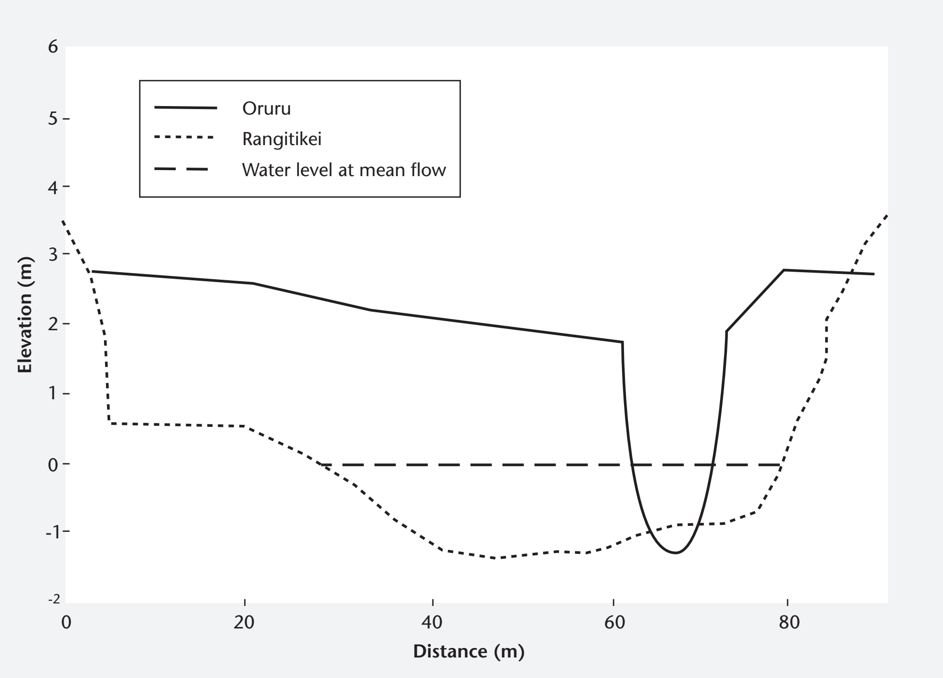
In larger floods which exceed the channel capacity, water spills out of and back into meander loops, so that the floodplain defined by the meander loops carries some or all of the excess flow.

Alternate bars are a feature often associated with the origin of meanders. These bars are gravel deposits positioned against both banks in a staggered manner. They can also exist independently of meanders, and are sometimes found in the near-straight reaches of meanders.

In low flow conditions, the inside bed of meander bends may be exposed, but there is generally a reasonably deep, slow-flowing channel on the outside of the bend. If alternate bars are present, they may also be exposed, leaving pools and shallow riffles.

Fig 7: Example of cross-sectional geometry of two rivers

The Oruru River in the Northland region is an example of a single thread uniform cross-section river. Width to depth ratio at its mean flow of 3.7 m^3s^{-1} *is in the order of 10. The Rangitikei river at the Mangaweka flow recording site is an example of a single thread non-uniform channel river. Width to depth ratio at mean flow of 63* m^3s^{-1} *is in the order of 40. Both river cross-sections are presented on a single graph below, to compare their cross-section geometry. The elevations of points on both cross-sections are relative to a water level of zero at mean flow.*



2.2.4 Braided channels

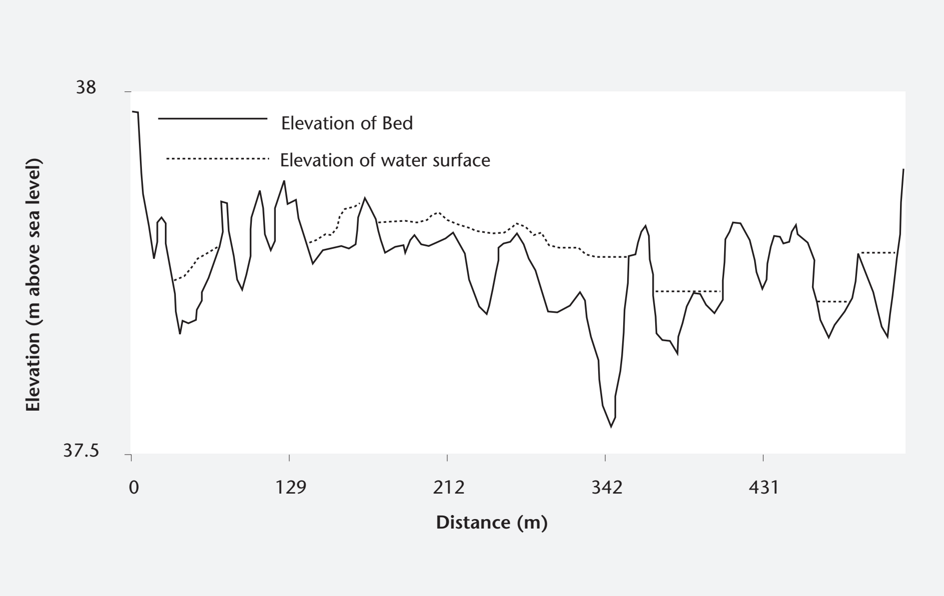
Braided channels are the distinctive morphological characteristic of many of New Zealand's gravel bed rivers, and are associated with high rates of bedload transport. They are self-formed and are believed to be the endpoint of an instability effect which initially creates a pattern of three or more rows of bars across the channel. There appears to be a limit to the development of braids, so that the channel reaches a dynamic equilibrium between flow regime and sediment transport processes (Mosley, 1992).

Compared to meandering, braiding is poorly understood. It occurs in particularly wide shallow rivers, and the number of braids goes up with the ratio of width to depth. This means that braiding is associated with high discharge and/or slope, and that the higher the discharge or the slope, the higher the number of braids. Braided channels usually flow bank-to-bank during the larger floods that are responsible for the braided form. However, in moderate freshes which do not cover the entire bed, sediment transport processes nevertheless continue to reshape the braids.

The plan form of braided channels at moderate and low flows is the distinctive multiple-thread active channels which often occupy areas across the whole floodplain. There are often riffles where braids divide, and the deepest water is found in braid confluences. As flows recede, the minor braids become shallow with low velocities even in the riffles. Some braids may dry up completely, but usually at least one major channel remains reasonably deep and fast-flowing.

Fig 8: Example of cross-sectional geometry of a braided river

The Ohau River in South Canterbury is a braided river. The water surface elevation shown here is for a flow of 100 m^3s^{-1}. *The mean annual flow is 80* m^3s^{-1}. *The cross-section illustrates how as flows recede, the minor braids become shallow with low velocities. Some braids may dry up completely. The central major channel remains reasonably deep and fast-flowing at low flows.*



2.2.5 Confined channels

In practical terms, the self-formed channels considered above exist only on dry alluvial plains (such as the Canterbury Plains). However, they also provide a limiting case in considering other river channels, in which the banks are more resistant to erosion than the bed alluvium and are therefore confined by their banks to some extent.

A meandering or braided river can be artificially constrained into a single straight channel, and many rivers have been engineered this way. This can also be caused naturally by valley walls or bankside vegetation. Another natural cause of confined channels is channel incision, in which the geological history has caused the river to erode a channel down into either bedrock (as is often the case in the steep upper section of rivers), or into historic alluvial deposits (which can occur when the downstream control on river slope in changed or lake or sea levels drop). Regardless of the cause of the restraint, the effect on channel form is in principle the same. The resulting channel form can best be explained by referring to the width-to-depth ratio.

A braided river restrained between two well-separated stopbanks or valley walls may still be braided. If the separation is less, the resulting lower width-to-depth ratio may result in a single-thread channel with alternate bars. That channel should then develop meanders, but the speed at which this happens will depend on how erosion-resistant the constraining channel is. Even rock gorges are typically meandering, but the migration of these meanders may be slow enough to ignore.

Most confined channels will develop alternate bars. When this occurs, the low-flow channel is non-uniform in cross-section and has a series of pools and riffles (as for unconfined channels). However, some rivers are confined so tightly that the width-to-depth ratio in floods is about 10. Here alternate bars do not develop and the channel has a uniform cross-section. The aquatic environment at low flow is then uniform, as for straight self-formed channels.

In reality, most rivers are constrained to some degree, either naturally or by stopbanks. It follows that alterations to the degree of constraint, such as the removal or establishment of bank vegetation, may result in changes to the channel form. For example, there are rivers with braided reaches in grassland and meandering reaches in forest.

2.2.6 Channels entrenched in bedrock with low bedload

Channels that flow through some geological strata carrying fine sediment as suspended load but little bedload. They do not fit into either the self-formed or constrained channels as described above, they are prevalent, however, particularly in the north of the North Island. These channels are generally entrenched in the bedrock, and are typically quite narrow. The channel form is dictated by the particular geological conditions, which may include sills of more resistant rock. At low flows these sills create a series of deep pools and riffles. In contrast, if the bed material has eroded more uniformly, a more uniform low-flow cross-section results.

2.3 The effect of variability in flood flow on channel morphology

The above discussion has assumed that all channel-forming floods are substantially the same size, but in general this is not so. It is generally assumed that floods of the order of the mean annual flood flow bank to bank and are the flows that determine the channel form. Flows of this size are thought to be instrumental in channel-forming and meander-migration (morphological) processes (Mosley, 1992). Larger floods are considered too rare to govern the long-term channel form, but they may in fact disrupt the established channel morphology at least temporarily.

The effect on channel form of a variable flood regime depends on the particular channel form. If a channel is near the meandering-braiding transition, different sized floods will tend to create different channel forms (Mosley, 1982). For example, the Selwyn River upstream of Whitecliffs has for most of its known history been a meandering river, albeit one that is close to the transition to braiding. A major flood caused a change to a braided form in 1951, but more gradually-acting changes resulting from more modest floods restored the meandering form over the following 30 years (Carson, 1984).

The ease with which these transformations occur may also depend on the amount of floodplain vegetation. When larger floods break out of a meandering channel, dense vegetation will slow water velocities and reduce the erosive potential. Rivers carrying sand and (especially) silt are likely to be entrenched as long as they are in the geological strata providing the sediment. Once they emerge onto a floodplain, these rivers are able to erode a wider channel with associated bars and bedforms. Whether they do so will depend on the nature of the bank material and the time available for an altered channel form to be established.

2.4 River mouth morphology

Many New Zealand rivers are closed to the sea at their mouths from time to time, and many small streams are seldom or never open to the sea. The immediate cause of river mouth closure is transport of coastal sediment by wave action. The flow regime has a significant effect, however, on the number and duration of closures, in that river flows are responsible for re-opening the river mouth and also prevent some closures.

The largest rivers are never closed to the sea, because their flow is sufficient to keep an outlet channel open in spite of material deposited by waves. However, if there are no physical restraints such as headlands, the mouth may migrate as well as change alignment if the ocean waves arrive at an angle to the coastline and move material along the coast into the mouth. In many rivers, such as the Rakaia, an existing mouth may close, but only as a new mouth breaks out. These events have sometimes led to a public perception that these large rivers can become closed to the sea.

Small streams on high-energy coastlines may be unable to ever create or keep an outlet channel. Such streams end in a lagoon or dune lake from which the water seeps through the berm.

In between these two extremes are many rivers and streams that are intermittently open to the sea. Although these occupy a continuum in flow rate (relative to ocean wave energy) it is convenient to separately consider:

- large rivers that are usually open
- small rivers or streams that are often or usually closed.

These two classes of river can both be affected by changes to the river regime, but it is different parts of that regime that are important. The modifying effect of a large lagoon is also important for both cases.

The general morphology is a bar that is a continuation of the beach either side of the mouth. The bar material is primarily that of the beach; the river sediment does contribute to the beach material, but there are many examples of gravel-bed rivers with their mouths on predominantly sandy coasts. Closure of the mouth is usually caused by longshore transport as waves arrive from an oblique direction to the coast. The bar is built out from one side of the mouth, so that the outlet channel becomes aligned towards the down-drift side, i.e. the same direction along the coast as the waves are travelling.

Perhaps the best way to visualise the changing morphology at a river mouth is to regard it as a contest between ocean waves and river flow. The usual role of waves is to reduce the size of the mouth or close it completely, whereas flows erode the berm material to widen and deepen the outlet channel. It is therefore useful in this context to refer to "large" and "small" rivers not in absolute terms but relative to the ocean wave regime. An important consequence is that mouth openings and closings are subject to the variability of both river flows and ocean waves, making their occurrence appear random. It is therefore not possible to, for instance, predict the exact consequence of reducing flood flow peaks, but the effects on the distribution of openings and closings (i.e. the river mouth opening regime) is in principle predictable.

A modifying factor to the balance between river flows and ocean waves is the lagoon behind the berm. If this lagoon is large enough, its storage can delay river mouth openings. However, once the mouth has opened, the prolonged high flows as the lagoon empties ensure that a wide deep opening is formed. Such openings are long lasting and very often tidal, which can help to keep the mouth open.

The progression of the opening process depends on the size of the lagoon, and also differs between sandy and gravel coasts. Openings usually start with piping failure, before the berm is overtopped. Wave action can sometimes halt the opening process but once a newly established outlet channel gets beyond a critical size, channel erosion acts to increase the flow rate, and vice versa. This effect is particularly marked for sandy berms, which can be carried away largely as suspended sediment.

The new outlet channel across a gravel berm differs from that across a sand berm due to the higher velocities needed to erode a channel in gravel. Because velocities high enough to erode gravels occur only in steep channels, the lagoon water level is usually above high tide level. Only the prolonged high flow from a very large lagoon (e.g. Lake Ellesmere) can erode a tidal channel in a gravel shoreline. In contrast, because channels through sand berms are easily eroded, they are generally tidal.

Table 2: Summary of categories of river mouth and their opening regimes

River mouth category	Sand berm	Gravel berm
Large river, small lagoon	Closures rare, occurring during low flows Short duration closures, usually long duration openings. Outlet channel wide and lagoon may be tidal Example: Kakanui River (North Otago)	Closures rare, occurring during low flows Short duration closures usually long duration openings Outlet channel narrow and lagoon non-tidal Example: Waiau River (North Canterbury)
Large river, large lagoon	Closures rare, occurring during low flows Duration of closure dependent on mean flow and lagoon area Long duration of openings Outlet channel and lagoon tidal Example: Karamea River (West Coast)	Closures rare, occurring during low flows Duration of closure dependent on mean flow and lagoon area Long duration of openings Outlet channel and lagoon may be tidal Example: Ruamahanga River (Lake Onoke) (Wairarapa)
Small river, small lagoon	Closures common Duration of closures dependent on seepage through the berm Duration of openings often short Outlet channel and lagoon may be tidal Example: Aropaoanui River (Hawkes Bay)	Closures common Duration of closures dependent on seepage through the berm Duration of openings often short Outlet channel and lagoon non-tidal Example: Esk (Hawkes Bay); Hinds River (South Canterbury)
Small river, large lagoon	Closures common, but not immediately after an opening Long duration of closures Moderate duration of openings Outlet channel and lagoon tidal Example: Okarito River (West Coast)	Closures common, but not immediately after an opening Long duration of closures Moderate duration of openings Outlet channel and lagoon may be tidal Example: Lake Ellesmere (extreme case) (Canterbury); Wainono Lagoon (South Canterbury)

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3. Biological Communities of Rivers

3.1 Introduction

Biological communities of rivers are mainly composed of autotrophs (periphyton and macrophytes), which use energy from the sun to form plant biomass upon which a second group composed of heterotrophs (bacteria and animals such as invertebrates and fish) directly or indirectly depend (Hynes 1970). The total mass of living material of any type (plants and animals) is termed biomass. The variation in species is termed diversity. The biomass and species diversity in rivers is a function of a number of physical and biological variables which vary at the reach scale (Allan, 1995). These variables are described in the following section.

3.2 Variables of importance to river biota

Physical variables that are of importance to biota can be divided into two categories:

- Hydro-physical variables
- Water quality variables.

3.2.1 Hydro-physical variables

Hydro-physical variables are reach-scale variables and are therefore the result of complex interactions and are highly variable in space and over time. These variables include:

- Velocity
- Depth
- Width
- Substratum (or bed sediments).

3.2.1.1 Velocity

Water velocity, and the associated physical forces, is an important environmental factor affecting biological processes in rivers. Velocity determines the fluid forces that are experienced by plants and animals. These forces strongly influence the anatomical and behavioural adaptations of biota (Poff et al., 1990, Jowett et al., 1991; Biggs, 1996b). Water velocity varies through the water profile, with very low velocities adjacent to the substratum and the highest velocities generally occurring near the surface. This velocity gradient, and the way it is affected by different bed roughness, is a fundamental factor controlling the local distribution of biota in streams (Goring and Biggs, 1996).

Velocity is affected by a combination of flow rate, depth, width, slope and bed roughness (Gordon et al., 1992). The effects of changes of flow on velocity will therefore be variable, depending on the channel geometry of a particular reach. Flow reduction may lead to increases in velocity in areas changing from a run to a riffle, and a decrease in velocity in pools or where a run structure is maintained. The reverse may apply to increases in flow.

Water velocity affects the size and concentration of suspended particles and the size of the bed material (substrata). Velocity also affects the delivery of the important gases (oxygen and carbon dioxide) and the delivery of nutrients to plants and food for animals (detritus for invertebrates and drifting insects for fish). The velocity of flow is critical for the respiration and reproduction of some species (Allan, 1995). Reductions or increases in water velocity can therefore impact positively or negatively on many biological functions.

Change in velocity changes the physical forces which govern the stability of bed material in the river channel and the resuspension of the solids in the water column. Increased velocities imply greater erosive potential and can result in greater movement of bed material (Carson and Griffiths, 1987). The inverse applies when velocities decrease, increasing the deposition of both fine and coarse particulate materials in a reach.

Increases in velocity above certain thresholds, can result in scouring of periphyton and invertebrate animals (Sagar, 1986; Biggs and Close, 1989). At velocities too low to move bed material, increases in velocity may be sufficient to slough periphyton from substrates (Biggs and Thomsen, 1995). Solids may be re-suspended by increased velocities, resulting in decreased light for plants (Davies-Colley et al., 1992) and difficulties in respiration and feeding for invertebrates and fish. Reductions in velocity increase stability of bed substrates and may lead to proliferation of plant material if other conditions are suitable (Biggs, 1996b).

3.2.1.2 Depth

Depth is affected by a combination of flow rate, width, slope and bed roughness. Changes in any of these variables can potentially alter river depth. Depth is an important hydraulic parameter, in determining whether hydraulic conditions result in a reach being a riffle, pool or run. Changes in depth in rivers can "drown" flow controls such as riffles, entirely changing hydraulic properties and therefore habitat conditions for biota in a reach.

Depth influences the living space available for biota, and changes in depth also may affect the habitat suitability of a reach for plants, invertebrates, fish and birds (Jowett, 1992a). Access for fish to the upper reaches of a river is related to depth (see below). The oxygenation of water in a reach by turbulence is affected by depth. Depth changes affect the temperature regime in a river (McBride et al., 1993). Shallow waters are heated to a greater extent by solar radiation than deep waters. Shallow waters also have greater surface area to volume ratios and therefore cool faster than deep waters in the absence of solar radiation. Depth changes may also affect light penetration to the river bed (Davies-Colley et al., 1993). Increased depth will reduce light levels and reduced depth will increase light levels.

One of the most critical habitat attributes for New Zealand freshwater fish is access to preferred habitats. Almost half of New Zealand's native species spend a phase of their life in the sea (McDowall 1990). Some of these species are found long distances upstream, and they undertake long migrations. Most of the upstream migrations is undertaken by juvenile fish, usually less than 70 mm long. Therefore, it is critical to the maintenance of fish populations that upstream access is not hindered by critically low flows, dams and other structures.

3.2.1.3 Width

The wetted width of river channels is directly important to biological conditions as it controls the total area available for bottom-living organisms. If there are no other restrictions, overall carrying capacity of periphyton and invertebrates will be a function of this bed (or habitat) area.

Changes in width (i.e. the wetted portion of the river cross-sections) predominantly occur as a result of changes in flow. This is related to changes in water depth and the ratio of change in depth to change in width varies considerably depending on the cross-sectional profile of a particular reach. The largest changes in width will occur in rivers with shallow cross-sections and the least reduction in deep cross-sections (see Figure 8). There may be a critical water level for a reach such that flow reductions down to this level will have little effect on width. Alternatively increased flow will have little effect on width up to the critical level. After the critical level is reached, increases or decreases of flow may result in comparatively large increases or decreases in width (see Figure 24 in Biggs, 1982).

3.2.1.4 Substrata

"Substrata" is an ecological term referring to the materials that make up the bed of rivers. This may include bedrock, boulders, cobbles, sand and silts, and also the plants and organic detritus which may occupy the beds and sides of river channels.

Determining of the importance of substrata in biological processes is complicated by its interaction with velocity. Substrata and velocity have significant roles in determining the types of biota occupying river reaches, and the interactions make it impractical to predict biological community composition on the basis of substrata alone (De Nicola et al., 1990).

Most river dwelling organisms live in close association with the substrata. Organisms may prefer various substrate sizes (e.g. sand, stones, silt) and types (e.g. rock or organic material such as detritus or living plants). Some organisms prefer river beds of gravel, cobbles or boulders living either on or under these substrata (Jowett et al., 1991; Quinn and Hickey, 1990a). For example, attached or encrusting forms of periphyton such as diatoms, require a stable substrata which is not easily overturned whereas macrophytes require fine material which their roots can penetrate for anchorage (Biggs, 1996b). Sands and silts are often a poor substratum for invertebrates because of tight packing of grains which reduces the interstitial spaces, and the availability of food and oxygen. However, some organisms such as worms and some midge lava (Chironomidae) are specially adapted to this type of substrate (Winterbourn, 1981).

Native fish and trout vary widely in their habitat preferences (McDowall, 1990). Some are free-ranging mid-water species in pools and runs, either solitary or in schools. Some rest on the substrata or amongst aquatic vegetation, mostly in slow flowing water. Others occupy spaces within the substrata, either amongst coarse gravels and boulders, within weedy instream debris aggregation or sometimes within soft sands and muds (McDowall, 1990). Species almost always have well-defined preferences for particular habitat and can be accurately and usefully characterised according to their preferences (Jowett, 1992a). Furthermore, fish have morphological adaptations for living in their preferred habitats that are so idiosyncratic that an experienced observer can often predict the type of habitat a fish comes from by studying body shape, fin shape and other obvious characteristics. Substratum conditions are of great significance for fish spawning, incubation and hatching, as many species create nests in finer substrata to provide protection and a constant flow of oxygenated water for eggs. Others species lay eggs on or under cobble-sized rocks (McDowall, 1990).

3.2.2 Water quality variables

Water quality is a reach-scale variable and is the result of complex interactions between hydrology, land use and geology (Close and Davies-Colley, 1990a, 1990b). Important water quality parameters include:

- Temperature;
- Particulate inorganic and organic matter;
- Dissolved organic matter;
- Dissolved ions, (e.g. bicarbonate, calcium, sodium, etc.);
- Dissolved nutrients (nitrogen and phosphorus);
- Gases (nitrogen, carbon dioxide and oxygen);

3.2.2.1 Temperature

The temperature of running water usually varies seasonally and diurnally, and between locations, according to climate, elevation, groundwater inputs, shade and flow rate, as well as human influences such as thermal discharges and abstractions. Streams in the upper part of catchments fed by groundwater sources or melting snow may have narrow temperature range. In the mid-catchment, streams may be small and unshaded, resulting in larger daily temperature variations as daytime incoming solar radiation and heat radiation at night increases the range. In the lower catchment, water temperature may be less variable as increasing depth-to-volume ratios inhibit absorption and radiation of heat (Allan, 1995).

Temperature is critical to biota, with ranges affecting growth rates (Bothwell, 1988) and extremes having lethal effects (Simmons, 1986). Many biota exhibit definite preferences in temperature range (Scott and Poynter, 1991), and temperature extremes can limit where a particular species will be able to survive.

3.2.2.2 Particulate matter

Suspended particulates (inorganic and organic) are often carried as part of the sediment load with many elements attaching to sediment at a molecular level by adsorption. Suspended particulate load is controlled by water velocity and sediment supply. Loads therefore tend to vary in accordance with the flow regime (Davies-Colley et al., 1993).

3.2.2.3 Dissolved organic matter

Dissolved organic material, nutrients and gases are strongly influenced by biological processes and therefore vary at the reach-scale according to biological activity. Sources of dissolved organic matter are terrestrial vegetation and animals which are deposited in the channel and dead aquatic vegetation and animals.

3.2.2.4 Dissolved ions

The total dissolved solids content of fresh water is the sum of the concentration of the dissolved ions which include calcium, sodium, magnesium, potassium, chlorine, bicarbonate and sulphate. Generally, more than 50 percent of the total dissolved solids is bicarbonate. This reflects the dominance of weathering and dissolution of sedimentary rocks in determining total dissolved solids concentrations (Close and Davies-Colley, 1990a, 1990b).

3.2.2.5 Dissolved nutrients

Phosphorus and nitrogen are the most critical nutrients for plants in rivers (Allan, 1995). The primary source of these nutrients is weathering of rocks and consequent release of inorganic phosphate and nitrate. In nutrient-poor fresh water, phosphate is often the principal factor limiting growth for plants. Theoretically nitrogen becomes limiting when the ratio of nitrogen to phosphorus (N:P) is below 16:1. In practice, however, the shift from phosphorus to nitrogen limitation occurs over a wider range (in the order of 10-30:1) (Allan, 1995). This is because certain cyanobacteria can fix nitrogen from the air and will typically increase in abundance in nitrogen limited conditions (Peterson and Grimm, 1992).

The water current increases mass transfer of nutrients for individual cells of plants in rivers. Uptake of nutrients is therefore also a function of water velocity with uptake rates generally increasing with increases in velocity until nutrients no longer constrain plant growth (Borehardt, 1996). Nutrient concentrations in rivers are a reach variable with concentrations varying widely in response to inputs and biological activity over the reach.

Nutrients are cycled in river systems from their original inorganic state, through uptake by plants, their subsequent consumption by herbivores, breakdown by microbes back to an inorganic state and uptake again. This is termed “nutrient spiralling”, with their direction of movement inevitably downstream (Newbold, 1992).

3.2.2.6 Gases

Oxygen, carbon dioxide and nitrogen occur in significant concentrations in river water. Nitrogen gas is of little importance biologically, but oxygen and carbon dioxide are of fundamental importance to biota (Allan, 1995). Oxygen and carbon dioxide enter river water through physical mixing, (especially in turbulent sections), and through the biological processes of respiration and photosynthesis. In smooth flowing rivers with little turbulence, biological activity is the main determinant of gas concentrations; in turbulent rivers, physical mixing is of greater importance (McBride and Rutherford, 1983).

In rivers with high plant biomass, carbon dioxide concentration decreases during daytime as plants use sunlight and dissolved carbon dioxide to photosynthesise organic material. Oxygen concentrations are elevated as oxygen is released as a by-product of this process. During the night the opposite occurs when photosynthesis ceases and plants, animals and microbes continue to use oxygen and release carbon dioxide during respiration. These variations in oxygen and carbon dioxide concentrations between night and day are termed Diel (24-hour) changes and are useful in estimating total biological activity (Allan 1995, McBride 1995).

Oxygen and carbon dioxide concentrations are also a function of water temperature (Allan 1995). As temperature increases the saturated concentrations of these gases decrease. Increased temperature reduces the oxygen concentration proportionally more than the carbon dioxide concentration. The Diel change in water temperature therefore has the reverse effect that biological activity has on the concentration of the two gases.

3.2.2.7 pH

The pH is a measure of acidity and alkalinity. A value of 7 is neutral. Values below 5 (acidic) or above 9 (alkaline) can be harmful to biota. Fresh waters vary in their pH due to natural causes and human influences. Decaying organic matter often results in brown or black acidic waters. Volcanic inputs, seepage of sulphurous or soda springs and industrial process can contribute to low (acidic) values of pH (Allan, 1995).

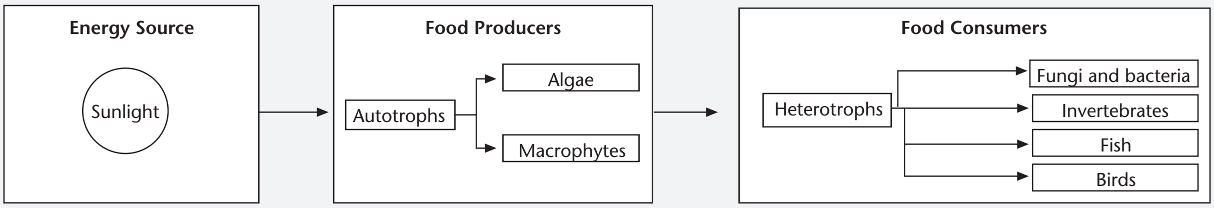
When carbon dioxide is dissolved in water a small proportion forms carbonic acid. Some acidity of river water is therefore a consequence of carbon dioxide inputs from animal and microbial respiration. The Diel variable in carbon dioxide resulting from daytime photosynthesis are therefore reflected in changes in pH, and pH increases (becomes more alkaline) during the day when concentrations of carbon dioxide are lower. The reverse occurs at night, (Allan, 1995).

Most natural waters contain bicarbonate and carbonate ions derived from solution of rocks. Bicarbonate is alkaline and neutralises acidic inputs. The process of neutralisation by the bicarbonates is known as buffering. This buffer system in rivers tends to resist changes in pH (Allan, 1995).

3.3 Biological energy systems in rivers

Biomass in river systems requires energy to sustain itself and to replace biomass lost from the system. The system which provides this energy is termed the food chain. The food chain represents the flow of energy from the primary producers (plants) to the energy consumers (herbivores and carnivores). These divisions in the food chain are often termed trophic (feeding) levels (Allan, 1995). The term "food web" represents a more complex model of energy systems and highlights the complexity of energy interactions. It shows that waste products and dead material for each trophic level are also internally recycled within the energy system (Allan, 1995). This section explains sources of biological energy for biological systems in rivers.

Fig 9: Flow of energy in river biological communities



3.3.1 Plants

Plants (autotrophs) use energy from sunlight to synthesise the organic compounds they need for growth, from CO_2, H_2O and nutrients in a process known as photosynthesis.

Plants in running water can be divided into two groups:

- Periphyton, which are non-vascular plants forming crusts, films or filamentous mats
- Macrophytes, which are large, vascular, rooted plants and bryophytes. (Which includes mosses and liverworts).

3.3.1.1 Periphyton (algae)

Virtually all surfaces receiving light in rivers sustain a periphyton community. Periphyton consists mainly of algae, (diatoms, green algae and cyanobacteria (blue-green algae)) and fungi. They are diverse in their habitat preferences and are therefore able to colonise a wide range of substrata. Periphyton often contains organic detritus, invertebrates and sediments. It can be categorised by its occurrence on stones (epilithon), soft sediments (epipelon) and plants (epiphyton). Epipelic species form mats or films on silts and mud bottoms and are therefore easily swept away by increased flow. Epiphytic and epilithic species are usually more firmly attached by secretions known as mucilage which enable them to withstand a greater range of water velocities (Biggs 1996a, Burkholder 1996, Stevenson, 1996).

Other factors which control the distribution and biomass of periphyton communities include light, temperature, current, hydraulic disturbances, nutrients and grazing by invertebrates (see chapters in Stevenson et al. 1996). The importance of any one factor in determining periphyton biomass depends on whether another factor is in shorter supply. For example, flood flow may limit biomass even if nutrients are plentiful (Biggs and Close, 1989).

Periphyton biomass is measured by sampling the community from a known area and determining the amounts of chlorophyll-*a* (a measure of the living plant material present) and the ash-free dry mass in the sample material (an indication of the total amount of organic material present) (Biggs and Close, 1989). The ratio of ash-free dry mass to chlorophyll-*a* is known as an autotrophic index. The autotrophic index is a useful measure of the health of the periphyton community. Values under 400 indicate a healthy growing mat. Very high values suggest the presence of more dead decaying material or other organic matter such as bacteria and fungi (Biggs, 1989).

Periphyton biomass in rivers has a number of fates. Consumption by herbivorous invertebrates is an important factor controlling biomass (Steinman, 1996). Biomass is also reduced, however, when river flow velocities increase, through sloughing (breaking off of vegetative material by increased shear forces) and scouring (abrasive removal through movement of substrate) (Biggs and Close, 1989). Biomass lost through this physical disturbance may form part of the detrital material in the system. Healthy cells also exude dissolved organic matter which is then used by other biological processes (Tuchman, 1996).

3.3.1.2 Macrophytes

Macrophytes in general occupy slow flowing water with relatively stable velocity and depth (Haslam, 1978; Biggs, 1996b). They are most abundant in medium-sized rivers, in back waters and along the margins of large rivers. Notable exceptions are the bryophytes which often grow in fast flowing streams with stable substrates (e.g. boulder streams). Factors which control the distribution and biomass of macrophytes are principally current and nutrients. Grazing by aquatic herbivores is generally considered to be unimportant. Macrophyte biomass is probably mostly consumed after it dies and becomes part of the detrital food chain (Allan, 1995).

3.3.2 Heterotrophs

Heterotrophs are organisms which obtain energy from consumption of other dead or living organic material. This includes microbes such as bacteria and fungi and animals such as invertebrates and fish.

3.3.2.1 Microbial heterotrophs

Detritus (particulate and dissolved dead organic matter) is an important energy input to river energy systems (Allan, 1995). Microbial heterotrophs (bacteria and fungi) break down organic material to release its energy. They are decomposers and detritivores, in contrast to herbivores, which consume living non-living material.

Detritus originates within the river as dead periphyton and macrophytes, animal faeces and released cellular material. It is also derived from terrestrial inputs such as leaves, soil and terrestrial invertebrates. Microbial activity operates on detritus of all size ranges.

Detritus energy pathways are of greatest importance in rivers where photosynthesis is restricted (e.g. deep or turbid rivers) or where there is heavy input of organic matter (perhaps from fall of leaf litter in autumn or point discharges of organic waste) (Allan, 1995). It has been suggested that this energy pathway is not as important in New Zealand rivers as the herbivore pathway because a predominance of non-deciduous vegetation limits detritus input, and relatively variable flow regimes flush detritus from river systems (Winterbourn et al. 1981).

Some species of small suspension-feeding invertebrates filter microbes as an energy source; they are in turn consumed by fish and by other invertebrates. Energy in detrital material is thus passed up the food chain (Allan, 1995). In breaking down organic material, microbes use oxygen and release carbon dioxide. This is an important reaction which can lead to reduced dissolved oxygen in rivers which are enriched with organic material (McBride and Rutherford, 1983).

3.3.2.2 Invertebrates

Invertebrates include all animals without backbones. In rivers this includes aquatic insects, larvae of insects with terrestrial (often flying) adult forms and mussels, clams, snails and worms that are aquatic throughout their life cycle. Energy sources for these invertebrate consumers include periphyton, bacteria, fungi, macrophytes and other invertebrates (Allan, 1995).

Invertebrate consumers are highly adapted to take advantage of this wide range of energy sources and can be subdivided into groups which reflect their feeding roles (see Table 6.1 in Allan, 1995):

- Gougers and shredders feed on woody and non-woody detritus, often from terrestrial sources. The ingested material may include microbes (fungi and bacteria) on the surfaces of the detritus.
- Suspension feeders collect fine particulate organic matter, especially bacteria and sloughed periphyton in the water column. These animals often have specialised filtering apparatus such as nets or secretions.
- Deposit feeders browse the surface deposits of fine particulate organic material especially bacteria and organic micro-layers.
- Grazers feed on periphyton by using rasping and scraping mouth parts. Piercing invertebrates have specially adapted mouthpieces which allow piercing and extraction of cellular material in macrophytes.
- Predator invertebrates feed on other invertebrates by biting and piercing. The feeding method of some invertebrates changes over their life cycle.

3.3.2.3 Fish

Fish differ from all the above biota in a number of ways. In particular, they are highly mobile, and so are not restricted by location. They can choose the best conditions in which to live and can change location and habitat conditions as their needs change, or if there is a harmful shift in habitat conditions, as in drought or flood. Thus where a change in water quality might lead to moralities of attached organisms, fish have the ability to move elsewhere in search of more compatible conditions (and perhaps reduce mortalities). However, fish may not move and may also suffer mortalities as a consequence of discharges of toxic substances.

Fish obtain their energy near the top of the food chain (Allan, 1995). There are herbivorous fish, though New Zealand had few naturally (possibly one periphyton browser, now extinct). Most of our freshwater fish are invertebrate predators and take their food either from the invertebrates drifting in streams or from the substrate. Several species however, obtain a high proportion of their energy by taking terrestrial invertebrates that fall on to the surface of rivers form the surrounding vegetation. This may be because many of our rivers may naturally (prior to deforestation) be darkly tannin stained, quite acid, and have low invertebrate productivity. Some fish live on other fish; this is the habit of large long-finned eels and introduced salmonid species once they reach large size (McDowall, 1990).

3.3.2.4 Bird use of river mouths

River mouths are dynamic and productive ecosytems inhabited by large numbers of birds of many species. For many of these birds, river mouths are an important place for them to feed, and some species are able to nest close to their main source of food. Consequently, river mouth closure may affect either or both of these aspects of the birds life.

Feeding

Each species of bird has a preferred method of feeding, and these may be classified into four major groups:

1. Aerial feeders - those that obtain most of their food while flying, usually by grasping in their bill prey just below the surface of the water. Examples of predominantly aerial feeders are black-fronted terns and white-fronted terns.
2. Divers - obtain their food by swimming underwater, for example black shags and little shags.
3. Dabblers - obtain their food by upending in the water and grasping food in their bill from off the bottom or from aquatic vegetation, for example black swans, mallards and shoveler ducks.
4. Waders - these species walk in or along the edge of the water and obtain their food by stalking, probing or pecking from the surface. This method is probably employed by the largest group of birds including white herons, bitterns, crakes, oystercatchers, stilts, godwits and dotterels.

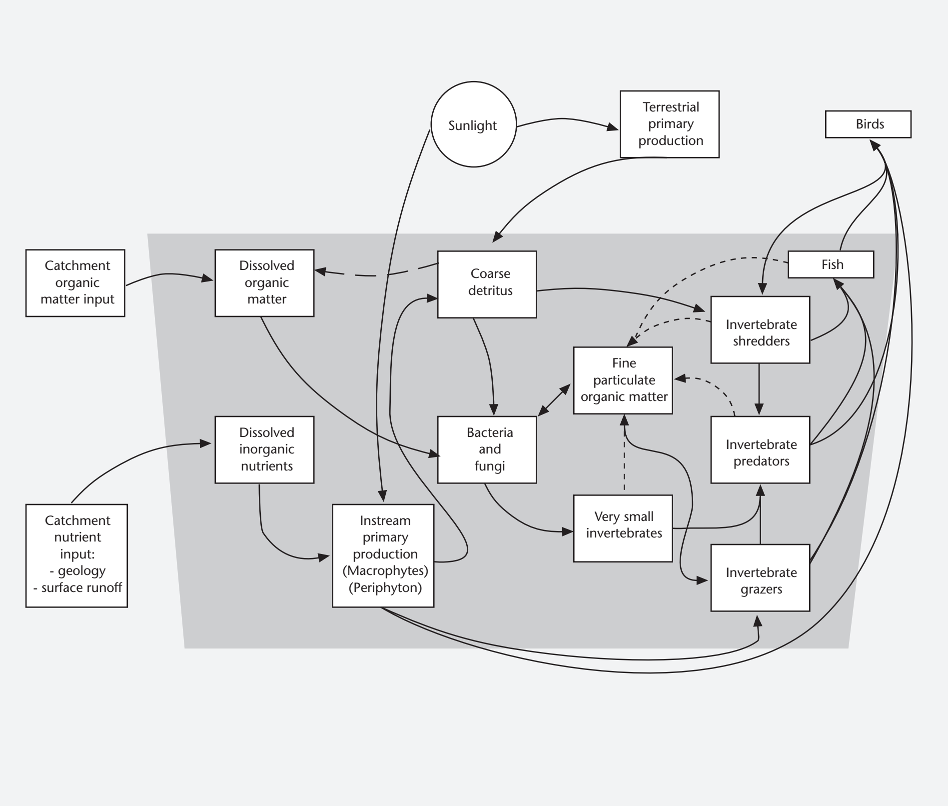
Species such as black-billed and red-billed gulls are generalist feeders and use more than one method to obtain their food.

Breeding

Several species of bird breed in coastal areas and the vicinity of estuaries. Many of these species nest on the ground, either as solitary (e.g. banded dotterel and species of duck) or colonial breeders (e.g. gulls and terns) and so are vulnerable to changes in water depth. Typically, colonial breeders make their nests on islands, which provide some protection from disturbance and mammalian predators. Solitary breeders nest on islands as well as the periphery of estuaries. The amount of cover provided by vegetation is important for ground-nesting birds, with each species having its specific requirements. For example, grey teal prefer hollows in trees, but wrybilled plover nest only on bare gravel. The amount and type of vegetation required by nesting birds generally also determines the distance they nest from the water's edge and so their vulnerability to changes in water depth. Nests of those species which require little or no vegetation are usually closer to the water's edge than those requiring vegetation.

Fig 10: Simplified representation of the biological energy system in a river

Dotted lines represent fine particles generated by feeding (e.g. faeces). Dashed line from coarse detritus to dissolved organic matter represents soluble organic matter leaching from detritus.



3.4 Fish passage through river mouths

Over half of New Zealand's 31 species of native fish are diadromous - they require access to or from the sea at some stage during their life. These species are listed in Table 3. If denied access to the sea, some species (at least four and possibly five), are able to adapt to a purely freshwater life history, but this usually occurs within lakes. It is not an alternative strategy which can be adopted if they can't get to the sea in any particular year.

Of the 19 species of introduced freshwater fish, only chinook salmon are regarded as an obligatory diadromous species. Both Atlantic salmon and sockeye salmon have formed landlocked populations within New Zealand. Seagoing brown trout are reasonably common throughout the country, although the majority of "sea-run" trout are probably estuarine dwellers (Jellyman and Graynoth, 1994). There are thought to be distinct stocks of such trout in some southern South Island rivers (Jellyman, 1991). However, spending part of their life at sea will not be obligatory for these stocks, and if denied access, they will adapt to life in fresh water.

Table 3 New Zealand diadromous freshwater fish species

Common name	Scientific name	Distribution	Ability to adapt to freshwater life cycle
lamprey	*Geotria australis*	w	no
shortfinned eel	*Anguilla australis*	w	no
longfinned eel	*Anguilla dieffenbachii*	w	no
mottled eel	*Anguilla reinhardtii*	l [1]	no
common smelt	*Retropinna retropinna*	w	yes
Stokell's smelt	*Stokellia anisodon*	l [2]	no
inanga	*Galaxias maculatus*	w	yes?
giant kokopu	*Galaxias argenteus*	w	yes
banded kokopu	*Galaxias fasciatus*	w	no
shortjawed kokopu	*Galaxias postvectis*	w	no
koaro	*Galaxias brevipinnis*	w	yes
torrentfish	*Cheimarrichthys fosteri*	w	no
redfinned bully	*Gobiomorphus huttoni*	w	no
common bully	*Gobiomorphus cotidianus*	w	yes
bluegilled bully	*Gobiomorphus hubbsi*	w	no
giant bully	*Gobiomorphus gobioides*	w	no
black flounder	*Rhombosolea retiaria*	w	no
chinook salmon	*Oncorhynchus tshawytscha*	l 3	yes

Key - w = widespread; l = localised
[1] *: distribution = top half of North Island (Taranaki - Hawkes Bay)*
[2] *: distribution = North and South Canterbury*
[3] *: distribution = Canterbury, Otago, West Coast (South Island)*

The complete life histories of all our native fish species are not fully known. We do know, however, that there is some migration in and out of rivers at all months of the year (Figure 11). The main period for downstream migration is autumn, whereas most upstream migration takes place during spring. The life stages (larvae, juveniles, adults) migrating at particular seasons varies considerably (Table 4). For example, upstream migrations in spring comprise juvenile bullies and whitebait, as well as adult lampreys and smelt.

Fig 11: Number of fish species migrating at different times of the year

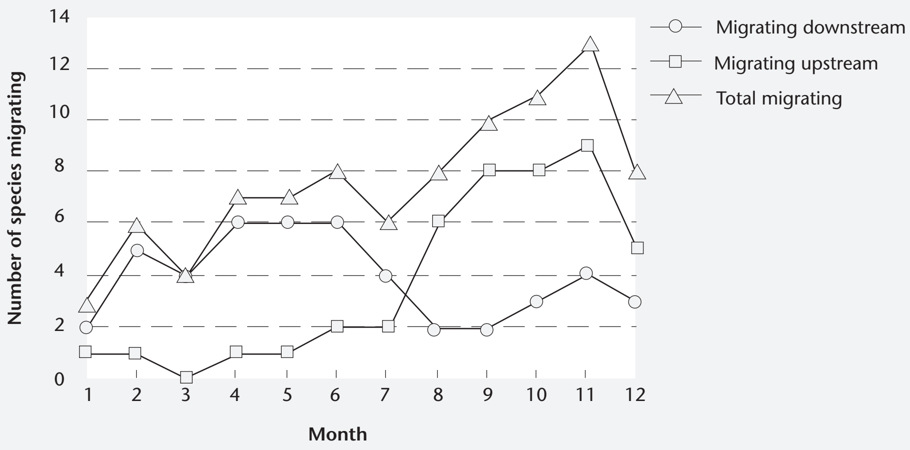


Table 4 Summary of migration periods of New Zealand's diadromous fish species

Species	Direction	Life stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Lamprey	Up	Adult						▓	▓	▓	▓			
	Down	Juvenile			?	░	▓	▓	▓	▓	▓	▓		
Longfinned eel	Up	Juvenile							░	▓	▓	░		
	Down	Adult				▓	▓							
Shortfinned eel	Up	Juvenile								▓	▓	▓		
	Down	Adult		▓	▓	▓								
Common smelt	Up	Adult										▓	▓	▓
	Down	Larva	░	░	▓	▓	▓	▓					░	░
Stokell's smelt	Up	Adult	░	░								░	▓	▓
	Down	Larva	▓	▓	▓	░								▓
Inanga	Up	Juvenile	░	░	░	░	░	░	░	▓	▓	▓	░	░
	Down	Larva	░	▓	▓	▓	░	░			░	░	░	░
Giant kokopu	Up	Juvenile											▓	▓
	Down	Larva					?	▓	▓					
Banded kokopu	Up	Juvenile								▓	▓	▓	▓	▓
	Down	Larva					▓	▓	▓					
Shortjawed kokopu	Up	Juvenile												
	Down	Larva									?	?		
Koaro	Up	Juvenile										▓	▓	▓
	Down	Larva			░	▓	▓	▓						
Torrentfish	Up	Juvenile				▓	▓	▓	▓	▓	▓	▓	▓	▓
	Down	Larva		▓	▓	▓	▓							
Redfinned bully	Up	Juvenile	░											▓
	Down	Larva								▓	▓	▓	▓	▓
Common bully	Up	Juvenile	▓	▓										▓
	Down	Larva									▓	▓	▓	
Bluegilled bully	Up	Juvenile	?										▓	▓
	Down	Larva	▓	▓							▓	▓	▓	▓
Giant bully	Up	Juvenile	?	?									?	?
	Down	Larva											▓	▓
Black flounder	Up	Juvenile									▓	▓	▓	
	Down	Adult												

Key

░	*periods of less intense migration activity*
▓	*probable main periods of migration*
?	*migration period uncertain*

Within seasons, migrations are also linked to environmental features such as floods and lunar phase. The upstream migration of glass eels is strongly linked to lunar period (Jellyman, 1979) and downstream passage of adults is associated with both floods and lunar phase (Todd, 1981). Eels also illustrate another feature of migration; those adults unable to reach the sea on their downstream spawning migration because of river mouth closure may be able to wriggle over the gravel berm if saltwater breaks over it. Such conditions sometimes occur in barrier lakes like Ellesmere and Onoke, especially during spring tides or strong southerlies.

3.5 Controls on riverine biological communities

3.5.1 Flow

As described earlier, river systems differ in flow regime. This catchment-scale variable controls reach-scale variables (water quality and hydro-physical conditions) and these, in turn, strongly influence the composition of biological communities (Biggs et al., 1990). Biological responses can be a function of physical controls at the smallest hierarchical level with the stability of individual particles, for example, influencing periphyton or individual invertebrates. Biological communities therefore vary considerably at the reach scale; however, this variation is thought to occur within the constraints provided by the catchment variables. The catchment variables of water quality and flow regime can therefore be used to explain broadly the biological response and community in a river (Biggs et al., 1990; Jowett and Duncan, 1990; Jowett, 1990; Quinn and Hickey, 1990a, 1990b).

Ecological models describe river biological communities as either “a tightly interwoven network of interacting species”, or alternatively “biological assemblages which persist simply because individual species are adapted to the environment”. (Poff and Ward, 1989; Hildrew and Townsend, 1987; Death, 1995; Death and Winterbourn, 1995). The former idea takes the view that biological forces maintain communities in equilibrium. The opposing view is that variable and unpredictable physical forces determine communities. The emerging ecological model of river communities suggests that some rivers are more strongly influenced by biological factors and others by physical factors.

3.5.1.1 Rivers where flow variability is low

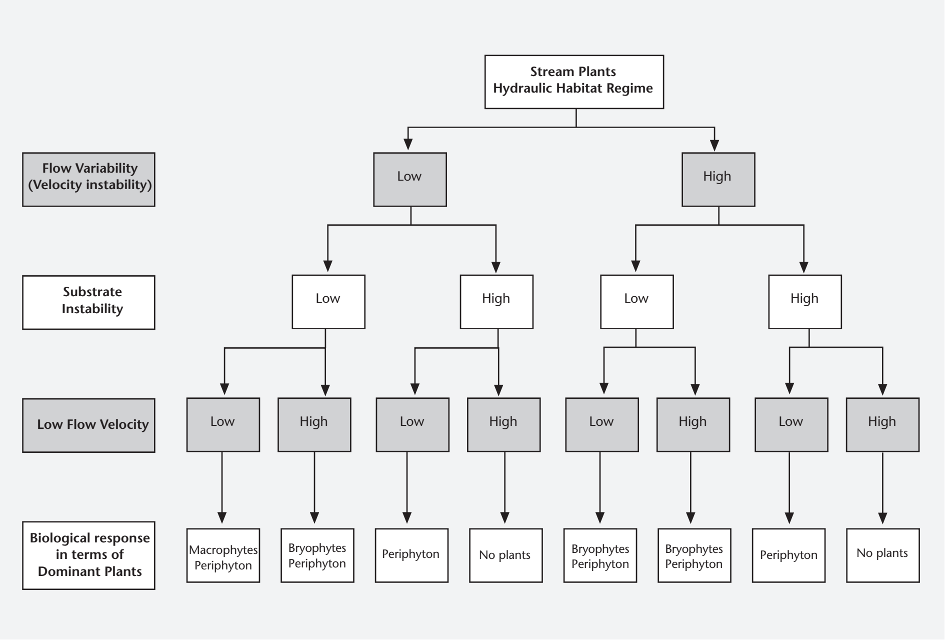
Where flow variability is low, such as in spring-fed streams, communities may be controlled by biological factors. Grazing and predation maintain equilibrium in species abundance and diversity. In this type of river, stable conditions allow a range of plant species to utilise specific habitats. This in turn encourages a wide range of invertebrate animals, some of which will be highly specialised to exploit a narrow range of resources. These specialist animals will tend to be non-moving (sessile) creatures remaining in their own specialised habitat. Stable conditions and predictable seasonal variations in conditions allow these animals to have time-specific development patterns and reproductive cycles.

3.5.1.2 Rivers where flow variability is moderate to high

Where flow variability is moderate to high, rivers are subject to harsh physical disturbance events (floods and droughts). Biological communities in these rivers are in a state of perpetual immaturity. Flood flows scour the substrata and wash away organisms. Droughts cause loss of habitat, and temperature and oxygen stress. Plant species in these environments will be limited by the physical conditions, and biotic interactions will be minor. Plants in rivers of this type are dominated by periphyton which can quickly re-establish after flood and low flow periods (Biggs, 1996b). The physical conditions also dictate the invertebrate species that can exploit the river. Irregular and unpredictable flows mean that rapidly colonising, generalist, species that can exploit a range of habitats and food sources will dominate the biological community. Flexible development cycles and mobile juvenile and adult forms allow for rapid re-colonisation of areas after floods and low flows.

Figure 12 illustrates how flow regime, through its effects on hydro-physical conditions at the reach scale, affects the hydraulic habitat that determines communities of river plants (Biggs, 1996b). Different plant communities dominate the various different habitats. Flow regime provides the highest hierarchical level in determining the biological response (in this case the type of vegetation present). Substrate instability and base flow velocity are the second and third hierarchical levels. These variables are dependent on flow regime and channel type.

Fig 12: River plant communities as a function of hydro-physical conditions (modified from Biggs, 1996b).



3.5.2 Nutrients

As noted previously, the energy supply available to successive trophic levels in a river community is the other factor which strongly influences the composition of that community. Nutrients and light control the growth of plants which then influences higher levels of the food chain. These plants can be algal communities (periphyton) or rooted aquatic plants (macrophytes). Dead plant material is also added to the river system from terrestrial sources and can form an important source of organic material to the animal community in the river.

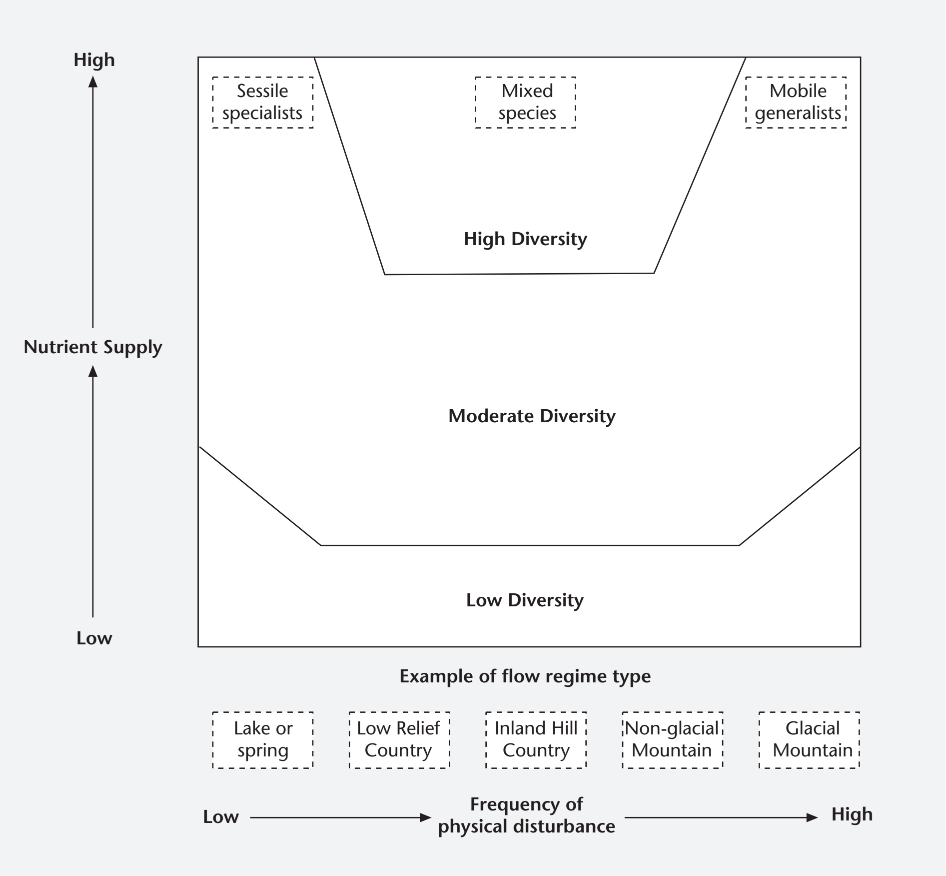
The availability of river plants and terrestrial sources of plant material influences the diversity and abundance of invertebrates in the community. Where light and nutrient resources are high and many different types of plant material are available, a diversity of specifically adapted invertebrates will be present to exploit each food source. Where food supply is low, such as in a river with low nutrients, aquatic plant growth may be limited to a few species with low biomass. This in turn limits the number of invertebrate animals that can utilise the resource. Ultimately fish species and numbers depend on the quantity and types of invertebrate animal in the community.

3.6 Biological communities as a product of food supply and physical disturbance

Rivers with very constant and very variable flow conditions represent extreme ends of the disturbance gradient. Between these extremes lie rivers which are subject to occasional disturbance and periods of stable conditions. These rivers will be colonised quickly after disturbances by mobile generalist species. As conditions stabilise specialist species which can compete effectively with the generalists for a narrow range of space and energy supply will establish in the habitat of their preference. Thus, rivers with a moderate degree of disturbance and high biological resources can probably support the highest species diversity (Hildrew and Townsend, 1987).

Diversity as a function of food supply and physical disturbance in rivers is represented by a continuum. This continuum is illustrated by the food supply - physical disturbance - invertebrate community diagram shown on Figure 13.

Fig 13: Nutrient supply — physical disturbance — invertebrate community diagram *(modified from Hildrew and Townsend, 1987)*



3.7 The temporal variability of communities in response to physical controls

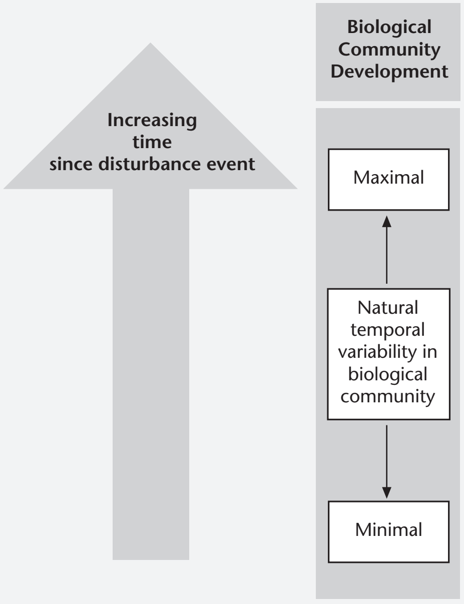
As has been discussed above, biological community structure is the product of a constant interplay between biological controls (mediated by energy supply) and physical controls (generally mediated by hydrological disturbance). A change in balance of these factors can result in changes in the abundance of different species over time.

Physical control processes in rivers result from hydrological disturbances (changes in flow). Flood flows result in increased velocity and corresponding shear stresses which can remove algal material through a process known as sloughing. Physical disturbance of the substrate also scours and flushes plant material and dislodges insects. Periods of low flow are also physical disturbances and will result in changes in communities. The mechanisms causing these changes are more complex than for flooding and are discussed later in this chapter.

River communities therefore move from a minimal level of community development, where mobile generalist species dominate, immediately after a disturbance to maximal development where biological interactions between a diversity of species dominates the composition of the community. Biological communities in rivers are therefore elastic systems with the ability to respond to changes in physical conditions without compromising the community structure in the long term. Figure 14 illustrates the biological and physical controls to which river communities are subject and the corresponding temporal changes in community composition.

The adaptation of an individual species or biological community to the physical disturbance regime of a river may make physical disturbance a functional requirement of that community. For example, trout are triggered to migrate upstream to spawn by small flood flows (spate or freshes). Physical disturbance is a functional requirement of the biological community. An example is the sloughing of periphyton growths by flood flows, as excessive growth can lead to habitat and dissolved oxygen limitations for invertebrates. Clearly where communities require physical disturbances for specific functions, the seasonal timing of these disturbances is an important factor.

Fig 14: Biological community response to physical disturbance controls



3.8 Do low flows limit biological communities of rivers?

It is often difficult to isolate the individual factors that limit populations of biological communities in any given river. Many studies have attempted to link stream fauna and its abundance to flow magnitude and most have failed to show any relationship. If the abundance of an aquatic species in a particular stream is limited by the naturally occurring low flows, then further reduction in flow would have a detrimental effect on that species. However, if the species is not limited by low flows, further reduction in flow will have minimal effect. However, intuitively there must be a point at which there is too little water in a stream for the continued survival of aquatic species.

Most native New Zealand aquatic fauna appear to be small stream and river species or their preferred habitat is on the edges of larger rivers. Few native fish are found in swift and deep water (at least now), although introduced fish occur in this habitat niche (McDowall, 1990; Jowett and Richardson, 1995). Stream insects are most abundant in shallow, swift habitats rather than the beds of deep rivers.

Because adult trout occupy habitat that requires the highest flow, they are the most likely to be affected by reductions in flow. Adult trout are rarely found in water less than about 0.4 m deep, but native fish are rarely found in water deeper than this (Jowett, 1990, 1992b). It could be argued that minimum flows that reduce water depths to less than 0.4 m in habitat preferred by trout would enhance native fish populations by excluding adult trout.

3.9 Habitat requirements and relationships with abundance of aquatic fauna

Most aquatic insect and native fish species are found in a wide range of rivers and streams, from large to very small. If anything, their abundance is inversely proportional to stream size. Studies of adult brown trout have shown that it is the quality of habitat at low flow that is more important than the quality of habitat at median or mean flows (Jowett, 1992b).

Recent studies of native fish (Jowett and Richardson, 1995) have also demonstrated they are more abundant in small streams than larger streams or rivers because the preferred habitat of native fish is usually for relatively shallow water. Similarly, stream insects are often more abundant per unit area in small streams than in larger streams (Jowett et al., 1991).

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4. Hydrological Effects of Change in Flow Regime

4.1 Introduction

Out-of-stream use of the water resource can lead to a change in the frequency, duration and timing of flows of a given magnitude and can therefore change hydraulic conditions. Changes in flow regime can also change flood flow magnitude and frequency which can lead to morphological changes. These changes in the frequency, duration and timing and magnitude of hydraulic conditions are fundamentally important in considering the instream effects of use of the water resource.

4.2 The effect of activities on flow regimes

Out-of-stream use of river water resources can be divided into four activities:

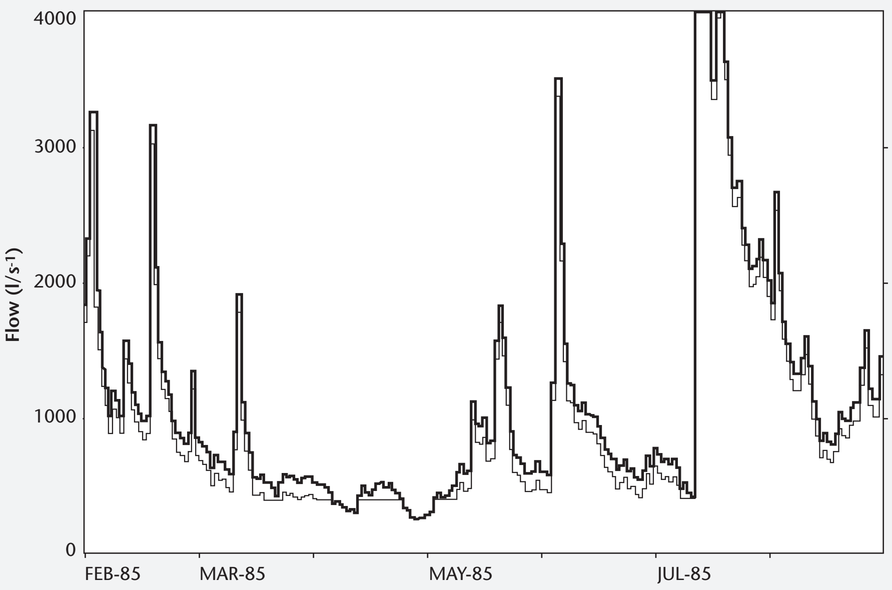
- Abstraction
- Damming
- Diversions into rivers
- Change in land use.

4.2.1 Abstraction

The rate of water abstraction (and abstraction of groundwater from aquifers adjacent to rivers) for water supply and irrigation is generally small in comparison to flood flows. Abstractions therefore tend to have most significant affects during periods of low flow, decreasing flows and extending the duration and frequency of flows below a certain value. An example of the effect of abstraction has on the flow regime is shown on Figure 15.

Fig 15: Effect of abstraction of base flow in the Kakanui River (Otago)

The upper line represents the natural flow recorded at the Mill Dam site. The lower line is the flow at Mill Dam that would occur under an abstraction regime that requires that flows in the river must not be reduced below 400 ls^{-1} by abstraction. An average daily abstraction rate of 130 ls^{-1} has been used to show how the volume abstracted becomes significant at very low flows but becomes relatively minor when river flows increase. Natural flows below 400 ls^{-1} do occur in this period of record but abstractions have been assumed to cease when flows are below 400ls^{-1}.



Abstractions affect the value of statistical measurements of the flow regime. Abstraction at low flows will generally increase the duration and frequency that flows are below a given value. This is shown on Figures 16 and 17 below.

Fig 16: 28-day low flow frequency analysis for the Kakanui River at the Mill Dam site

The upper line is the low flow frequency for the natural flow. The lower line represents the low flow frequency that would occur under an abstraction regime that allows an average instantaneous abstraction of 130 ls^{-1}. The figure illustrates that the effect of abstraction is to increase the probability of occurrence of a given minimum river flow.

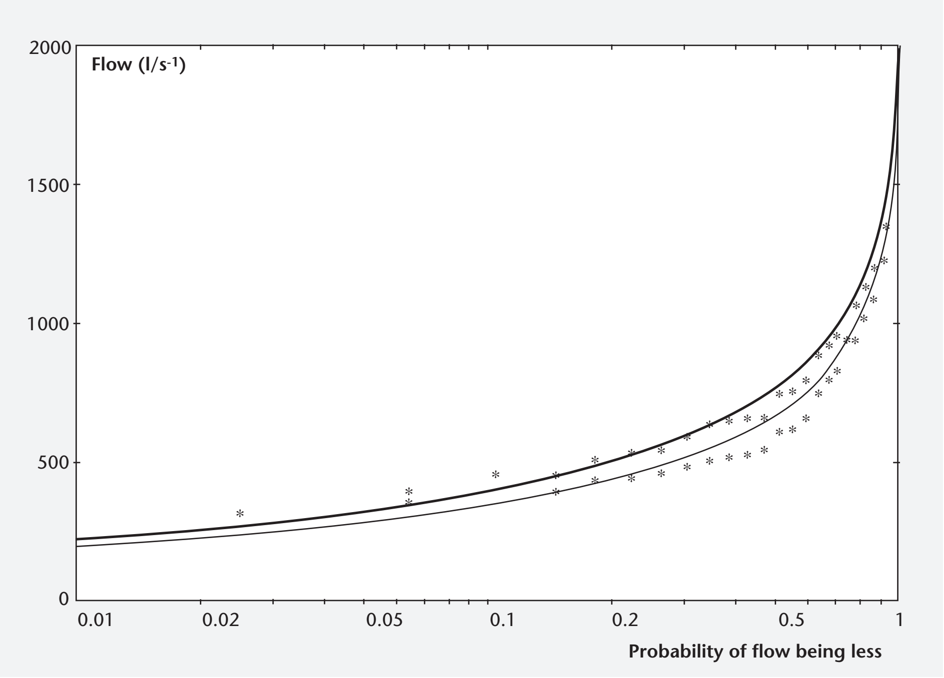
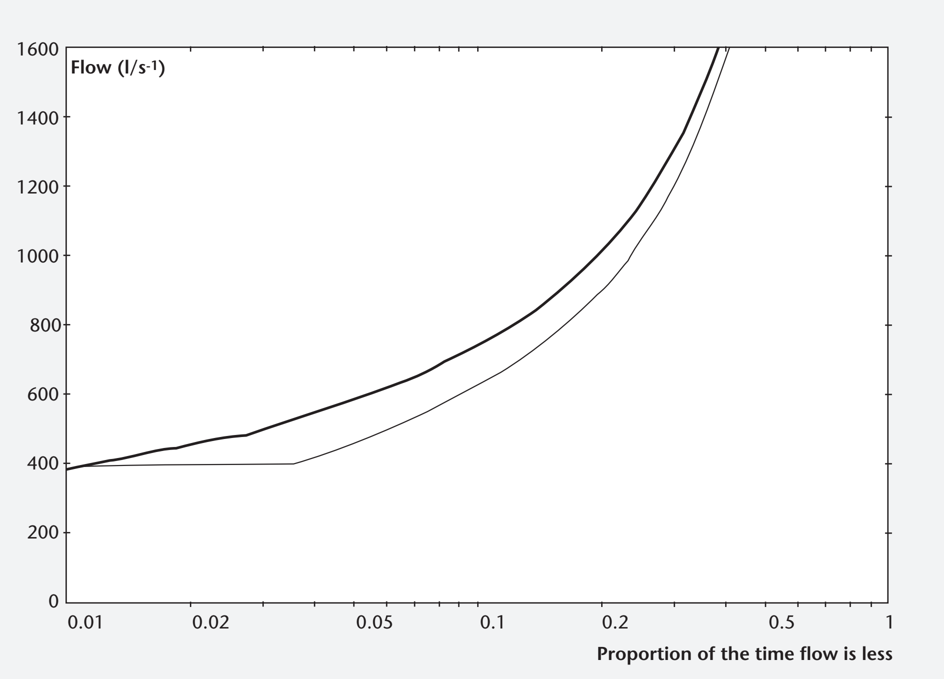


Fig 17: Flow distribution analysis for the Kakanui River at the Mill Dam site

The figure illustrates that the effect of abstraction is to increase the duration that the river is below a given flow rate. The upper line is the distribution of flows for the natural flow. The lower line represents the distribution that would occur under an abstraction regime allowing an average instantaneous abstraction of 130 ls^{-1}*. It has been assumed that the abstraction regime requires that flows in the river must not be reduced below 400 ls*$^{-1}$ *by abstraction, therefore the lower flow distribution curve flattens off and meets the natural flow distribution curve at a flow of 400 ls*$^{-1}$*.*



4.2.2 Dams

Dams can significantly alter the whole of the natural flow regime. Storage volumes of dams can damp flood flows resulting in reduced flood magnitude and frequency. Management of release volumes and the natural buffering provided by storage volumes can result in relatively constant base flows. Flow constancy may result in minimum flows that are either greater or smaller than the natural regime.

Fig 18: Effect of damming on the flow in the Hawea River immediately downstream of Lake Hawea

Lake Hawea is artificially raised and the discharge is controlled by gates for hydro-electric power generation. The dark line represents the inflow to the lake storage. The light line is the discharge. During periods of high flow into the lake, the discharge is reduced to a minimum flow to store water. During periods of low flow the discharge from the storage is increased to augment flows downstream and provide generation capacity. The resultant downstream flow regime is therefore entirely controlled by the management of releases for the storage and is effectively the reverse of the natural flow regime.

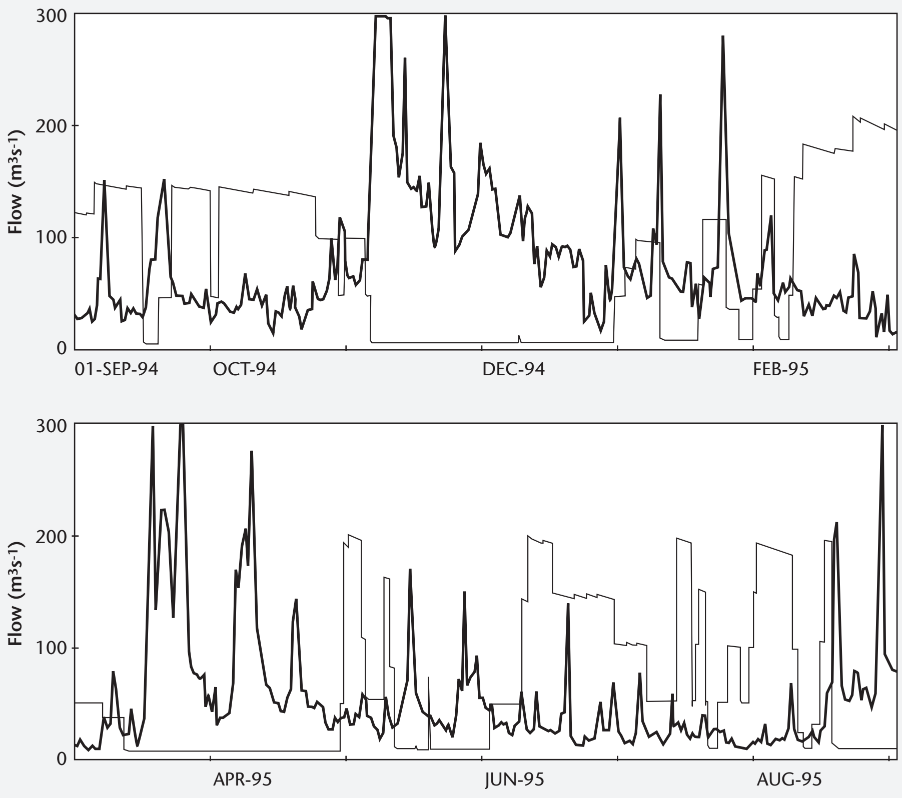


Fig 19: Effect of damming on flood frequency in the Hawea River immediately downstream of the control gate

The upper line represents the frequency of peak flows into the lake storage.
The lower line represents the frequency of peak flows out of the lake storage (i.e. in the Hawea River). The graph shows that flood peaks into the lake are significantly greater than flood peaks downstream of the lake outlet (flows are in m3s^{-1}).

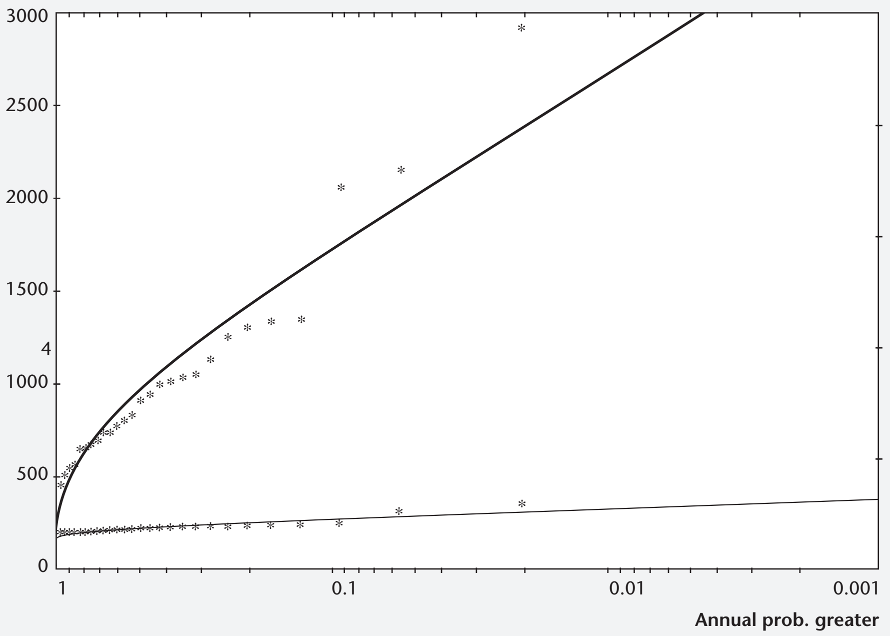


Fig 20: Effect of damming on minimum flow frequency in the Hawea River

The upper line represents the frequency of low flows into the lake storage. The lower line represents the frequency of low flows out of the lake storage (i.e. in the Hawea River). The graph shows that the variability of the outflow is considerably less than the variability of the inflow (flows are in m^3s^{-1}*).*

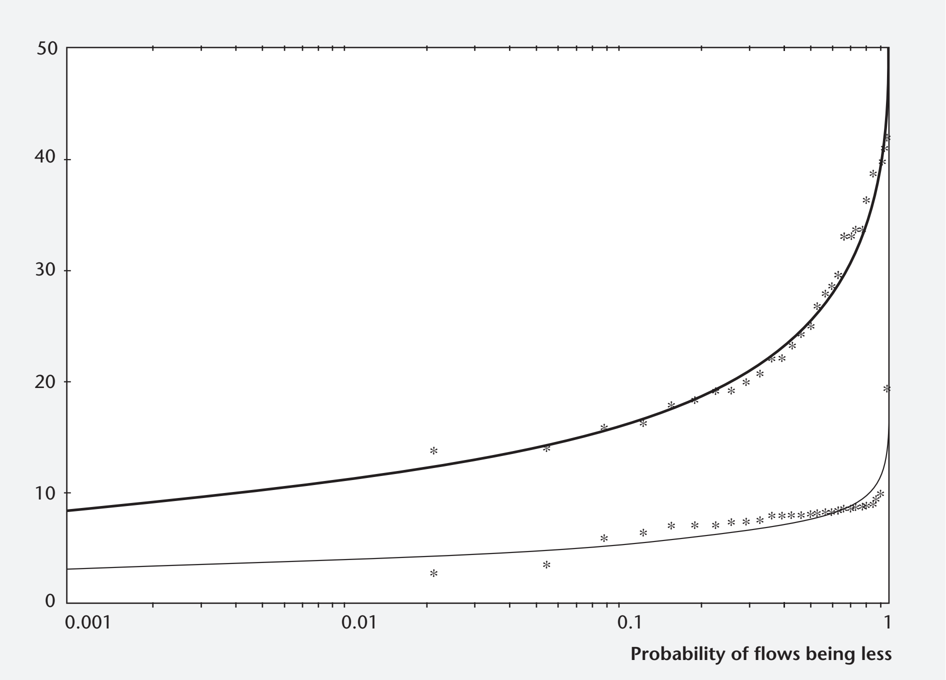
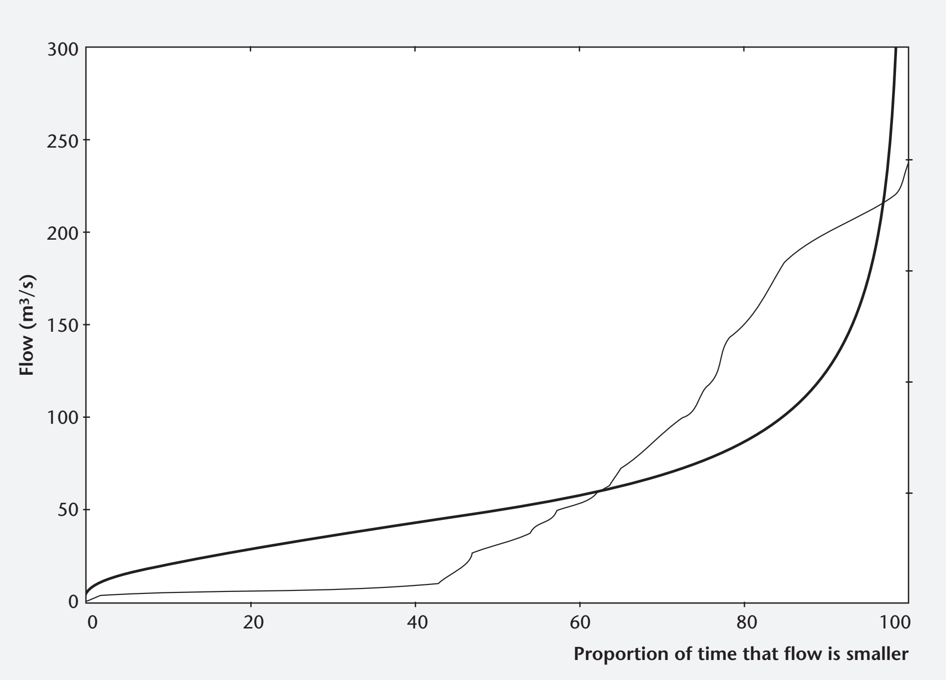


Fig 21: Effect of damming on flow duration in the Hawea River

The heavy line represents the distribution of natural inflows into the lake. The light line is the distribution of the outflow, illustrating the effect of the managed discharge from the dam.



4.2.3 Diversions into rivers

Diversions generally have the effect of increasing base flows and therefore produce a less variable flow regime. Flood flows are not generally significantly altered, as diversion works will have a design capacity that will not be exceeded.

4.2.4 Land use changes

It is widely accepted by hydrologists, and supported by numerous scientific studies (Bosch and Hewlett, 1982; Fahey and Rowe, 1992; Duncan, 1995; Stednick, 1996; Duncan, 1996), that replacing short vegetation like pasture or tussock with tall vegetation such as pine trees will reduce annual water yield. Conversely, clearing scrub or clear felling forests will increase annual water yield.

The following average changes to annual water yield can be expected for the following land use changes to 100 percent cover of closed canopy trees (based on catchment studies in New Zealand) (Table 5). The number of years of data on which the percentage is based is also included to give some idea of the reliability of the data. The range of the reductions is also given to show how the reductions may vary from year to year and place to place.

Table 5 The average effect of land use changes on catchment water yield

Land use change	Mean water yield	Range %	Years of data
Pasture to pines	56%	33 - 81	30
Tussock to pines	38%	29 - 45	7
Scrub to pines	37%	-29 - 74	19
Native forest to pines	16%	11 - 25	7

Land use change affects the whole flow regime, so high and low flows as well as the mean flow will be affected by changes in land use. However, there is also evidence to suggest that the more extreme the high or low flow, the less it will be affected by catchment vegetation changes. Figure 22 shows mean runoff hydrographs from each three of pine and pasture covered catchments in Nelson, for a large storm. The flood peaks for the pine catchments averaged 32 percent of those from the pasture catchments. In Figure 22, even when the flows are low there is still a difference in the flows from the two catchment cover types. The effects of afforestation of pasture catchments on flood annual exceedance probability (AEP) are shown in Figure 23. Again, each line represents the average from three catchments. The plots indicate floods from pine catchments can be expected to be smaller than those from pasture catchments over a wide range of AEPs with smaller floods being reduced by the greatest proportion.

The effect of afforestation on low flows is illustrated in Figure 24. The flow duration curves show the relative flow rates from semi-mature (closed canopy) pines and pasture over eight years. For much of the time flow from the pine catchments is about 25 percent of that from pasture catchments. When pastoral catchments with small perennial streams are completely afforested, streams may become ephemeral and ephemeral streams are likely to be dry for longer. In the Moutere Hills, Nelson, small (4.0-7.7 hectare) pasture catchments had streams which were dry on average two months/year. Similar catchments with closed canopy forest were dry for three months/year more than the pasture catchments (Duncan, 1995).

Fig 22: Hydrographs of runoff from Nelson pine and pasture catchments for the flood of 30 June 1980

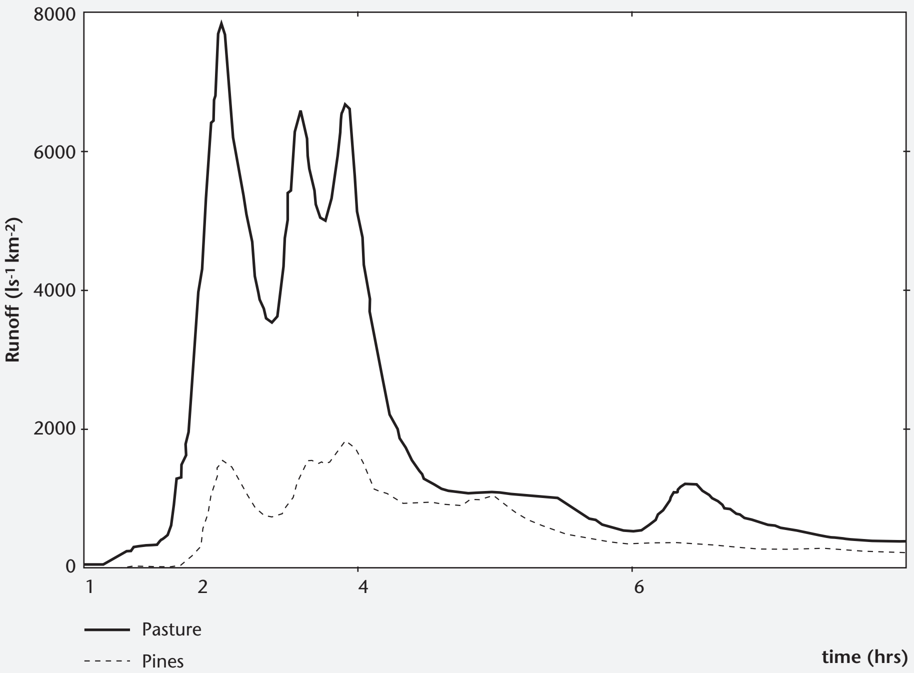


Fig 23: Relationship between annual peak flow and return period for catchments that were either predominantly pasture or gorse/pines between 1964 and 1993

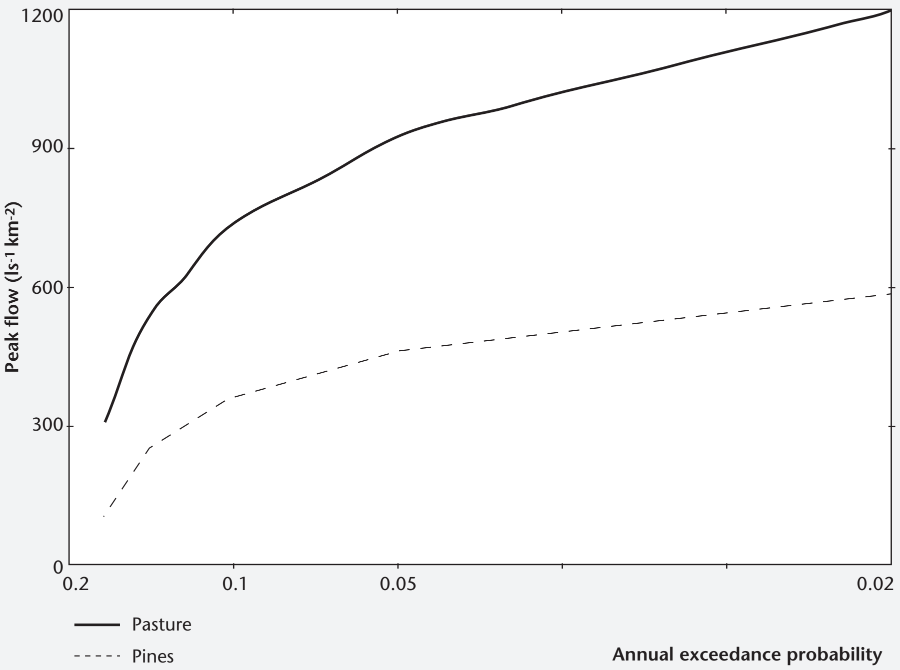
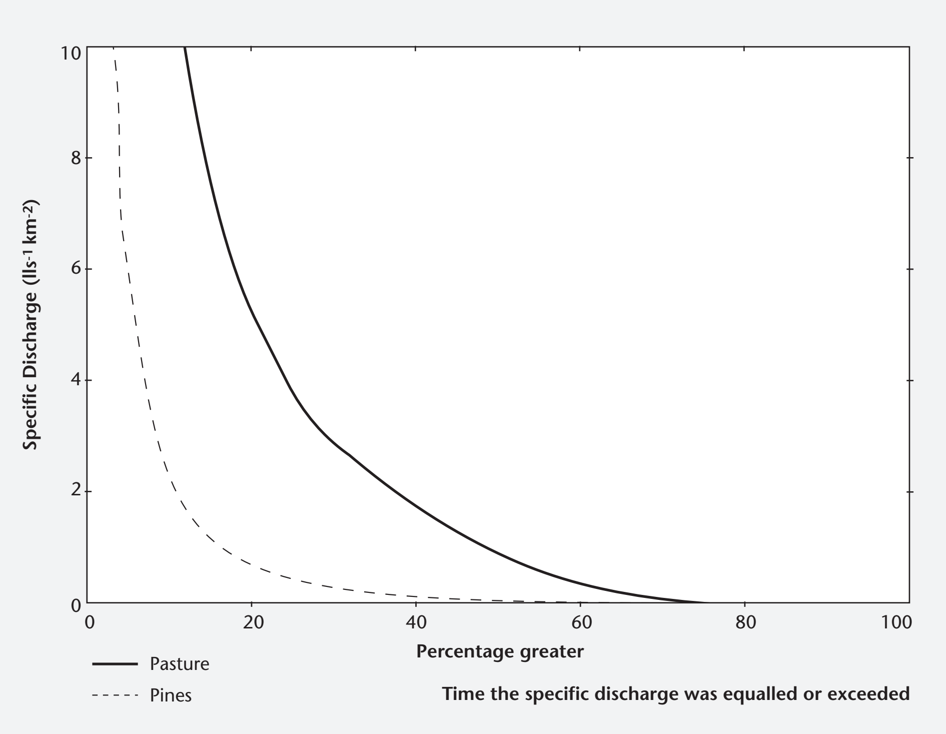


Fig 24: Flow duration curves for 1978-85 from mature pine and pasture catchments



Where a large forest is being considered, part of which is being logged and replanted every year and some of which has partial canopy pines, flow reductions would not be as large as indicated above. Assuming a 28-year cycle from planting to harvest and equal areas of each age class, planting pasture with pines would give about a 45 percent reduction in flows and planting scrub in pines would increase flows by about 8 percent (assuming scrub clearance before planting by burning or line dozing. The increased flows due to scrub clearance and at harvest more than make up for the reduced flows when the forest canopy has closed).

Afforestation of pasture also has the potential to reduce the amount of deep water drainage to aquifers. In low rainfall areas such as the Moutere Hills of Nelson this possibility has led to changes to the District Scheme, restricting the proportion of a land holding which can be afforested.

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5. The Hydraulic and Morphological Effects of Change in Flow Regime

Change in flow regime alters the magnitude, duration and frequency of occurrence of particular hydraulic conditions. These changes can be temporary hydraulic changes that are reversed when flows increase, or semi-permanent morphological changes which alter hydraulic conditions for the entire flow regime because channel geometry changes.

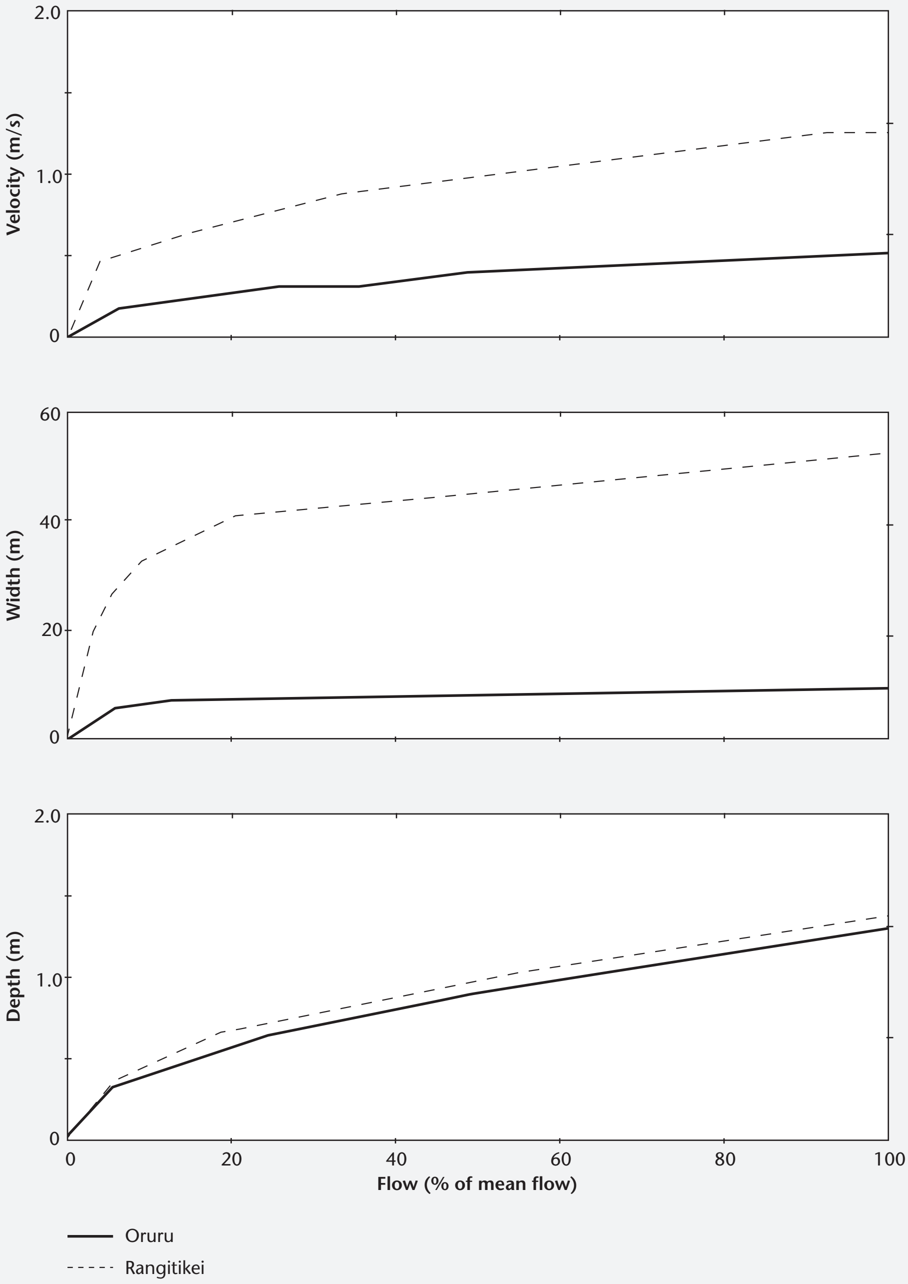
5.1 Hydraulic changes

The hydraulic effects of change in flow regime differ for different river types. These differences can be explained by considering the natural flow regime and channel type (Biggs, 1981, 1982). Where flow regimes are stable, abstraction will result in a stable, near constant flow reduction relative to the natural flow. Because base flows comprise the majority of the total flow volume in rivers with stable flow regimes, the natural flow volume may be significantly reduced. Abstraction from rivers with variable flow regimes will result in large reductions relative to natural flows during low flow periods and very small relative reductions at times of high flow. Because flood flows comprise the majority of the total flow volume in rivers with variable flow regimes, the natural flow volume may not be significantly reduced by abstraction.

Uniform channels have low width-to-depth ratios. There is therefore a disproportionately large reduction in depth compared to width when flows are reduced. In U shaped channels width may be virtually unchanged when depth is lowered. The opposite applies to non-uniform channels. These have high width-to-depth ratios and therefore width changes to a greater extent than depth with change in flow. This is illustrated in Figure 25.

Fig 25: Variation in hydraulic conditions with flow

The three graphs below illustrate the change in the value of hydraulic conditions of depth, width and velocity in the Oruru and Rangitikei Rivers as a proportion of the mean flow (refer to Figure 2.1b). The Oruru River has a single thread uniform channel and the Rangitikei River has a single thread non-uniform channel. The channel cross-sections are illustrated in the River Systems Chapter. It can be seen that width changes at a relatively higher rate with change in flow in the Rangitikei River than the Oruru River. Width is almost invariant in the Oruru River until approximately 7 percent of the mean flow. Velocity also changes at a higher rate with change in flow in the Rangitikei River. Depth shows a similar change with change in flow for both rivers.



5.2 Morphological changes

Dams which dampen flood flows will also generally change the sediment transport regime of a river, such that the river bed below the dam is likely to degrade (lower in bed level) and sediment sizes are likely to coarsen. Dams and diversions can also alter morphological processes when dominant flood flows are changed and sediment supply is changed. Reducing the sediment supply and the frequency of flood flows will tend to stabilise channels. Braided channels may adopt a single-thread meandering form. Meandering channels are likely to become more stable with a reduction in the rate of migration of channel meanders. The inverse applies when diversions are made into a river system. Morphological changes can be considered to be semi-permanent as dams and major diversions are significant infrastructure which are unlikely to be removed.

Another mechanism that can change morphology is constraint of the channel by increased riparian vegetation. Where flood flows are significantly reduced, riparian vegetation can establish in the active bed. This can confine flood flows and increase bank stability. The effect can be to reduce the sinuosity of meandering channels and reduce the number of channels in braided rivers (Biggs, 1982).

5.3 The effect of change of flow regime on river mouth opening

To assessing the effect of flow regimes on river mouth closure, rivers must be categorised as large or small relative to the wave energy at their mouths. A river mouth lagoon can be categorised as large or small depending on the relative difference between lagoon volume and flood size. The combination of these two factors can be used to categorise a river mouth. To categorise river mouths, the following steps are recommended:

- Determine from local knowledge or observations how often openings and closures occur, and for what percentage of the time the mouth is typically open. In particular, attempt to determine the typical flow conditions when openings and closures occur. From this information it should be possible to categorise the river flow as “large” or “small” relative to the ocean waves by roughly equating these to “usually open” and “usually closed”. If there are no flow records for the river, examining the record from another river in the same region can help determine the frequency of floods and freshes.
- Determine from local knowledge or observations the typical lagoon water levels when closures occur and when openings occur, and use the difference in levels and the lagoon area to calculate a storage volume.

- Estimate flood volumes and peak flow rates for typical flood events (using regional methods if no flow records exist for the river).
- Estimate a representative low flow (using regional methods if necessary).

Determine from the above information (i) how many floods would be needed to refill the lagoon and/or (ii) how long it would take for low flows to refill the lagoon. If more than one flood is needed, the coastal lagoon of a "small" river can be considered "large". If it takes more than a couple of weeks for low flows to refill the lagoon of a "large" river, then the lagoon can be considered "large".

5.3.1 Large rivers (relative to wave energy)

Rivers that are usually open to the sea are at risk of closing when wave energy is high (especially when the waves arrive at an angle to the beach) and flow is low. Following closure, river water may be stored in a lagoon, which rises in level until it breaks out through the berm. How long this takes depends primarily on the size of the lagoon, as flow through the porous berm likely to be relatively minor.

Of possible modifications to the flow regime, reduction of low and base flows has the most effect on these river mouths. The difference between what are termed "low flows" and "base flows" in this discussion is related to the actual mechanisms which allow river mouths to open.

5.3.1.1 Small lagoon

If there is no lagoon or the lagoon is small, a flow of a certain magnitude will be required to maintain an open mouth. Flows below this are "low flows" and the magnitude, and frequency of closure will depend on the wave energy at the mouth. Where the lagoon is small, it is reasonably quickly filled by base flows, so that the duration of closures is also sensitive to changes in base flow; almost any fresh is likely to cause an opening, so that modifications to the flood flow regime have a relatively minor effect. If a large river never or seldom closes, a significant reduction in extremely low flows may allow closure, or increase the frequency of closures.

5.3.1.2 Large lagoon

If there is a lagoon at the river mouth, the volume required to fill the lagoon and cause a break-out of the mouth is important. The arrival of a flood may supply this volume immediately, but otherwise the base flow volume over a period of time is the important aspect of the flow regime. The duration of the base flow that is important depends on the lagoon volume and the wave energy at the mouth. The duration of river mouth closure is likely to be increased where an activity significantly reduces base flows over long periods of time.

5.3.2 Small rivers (relative to wave energy)

5.3.2.1 Small lagoon

Small rivers that are often closed are typically opened by flood events. If the coastal lagoon is small, alterations to the frequency and magnitude of floods will therefore have the most significant effect on the proportion of the time that the river is open, by affecting the frequency of openings. Damming of the main river or a significant tributary may therefore prevent some or all openings from occurring. On the other hand, the drainage and stop-banking of river plains normally inundated by flood flows may cause more frequent openings by conveying to the mouth flood peaks that would previously have been lost to storage. Alteration to the low and base flow regime will have little or no effect, because base flows are unable to keep the mouth open anyway.

5.3.2.2 Large lagoon

If the coastal lagoon is large, a single flood may not provide enough water to cause a break-out. The frequency of openings is then determined by the length of time that it takes for the lagoon to fill, which will depend on the base flow volume as well as the size and frequency of floods.

5.3.3 Seasonal variations

It is difficult to determine whether the effects of alterations to the flow regime have more significant effects at a particular time of the year. Firstly, the ocean wave climate may vary seasonally. There is only limited wave data for New Zealand coasts, but wave modelling from meteorological information is now at a stage where it can provide useful information. Secondly, the effect of the modification will depend on the particular set of circumstances. For example, reducing flood peaks in a “small” river will have no significant effect if conditions were such that no opening was likely anyway, but the effect may be highly significant if just one opening would have occurred but was prevented.

Some generalisations can be made about natural seasonal variations:

- Many New Zealand rivers have reduced low flows in summer, so that “large” rivers may close more frequently then.
- Rivers with a significant high country catchment may have reduced low flows in winter, as water is stored as snow and ice. On the east coast of the South Island, this will generally coincide with higher wave energy, so that closures of “large” rivers are more common in winter.
- In a large coastal lagoon, evaporation in summer may be a significant consideration. Openings may be rarer in summer than in winter because lagoon levels rise more slowly.

To evaluate these variations they need to be examined alongside the proposed alterations to the flow regime and the particular set of circumstances. However, New Zealand's climate is *relatively* free from seasonal variations, so that some of the effects may be quite subtle.

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6. The Ecological Effects of Changes of Flow

6.1 Introduction

Chapter 3 of this volume, Biological Communities of Rivers, discusses how flow regime is a major determinant of biological communities in rivers. Flow rate dictates the rate at which oxygen and energy supplies are delivered to plants and animals. It also dictates the quantity and type of aquatic habitat that is available. Variation in flow also produces disturbance events which lead to temporal changes in the biological community structure. Flow changes affect hydraulic conditions at the reach-scale and, through changes in physical conditions referred to here as modes of impact, cause a variety of responses by the biological community

6.2 Biological responses to changes of flow regime

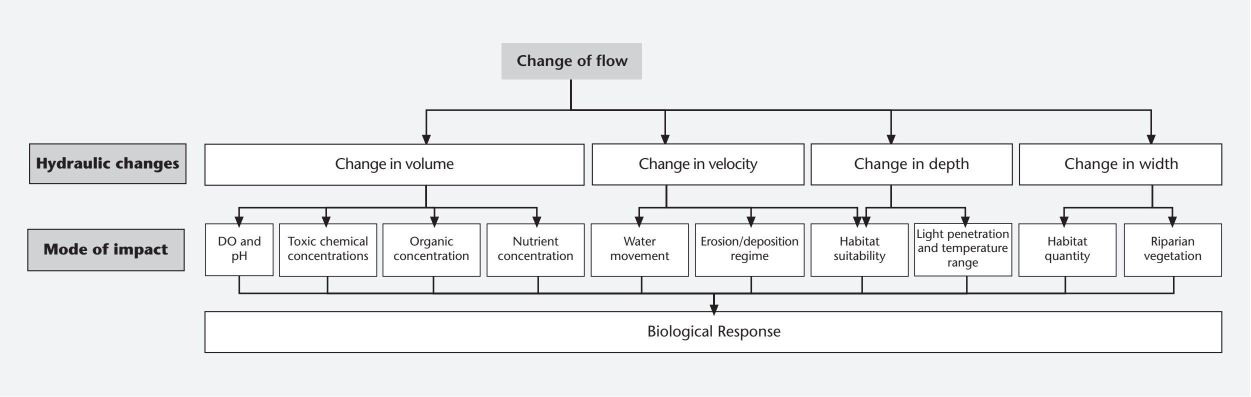
Changes in flow regime by out-of-stream use of water lead to the same biological responses as natural changes in flow. However, human interference can result in biological community variations that are larger, of longer duration and more frequent than those caused by natural circumstances.

If the change in flow regime is large enough, it may also cause permanent changes in the composition of the biological community. This occurs when the flow change alters characteristics which are important for the sustained abundance or existence of a species. Biological requirements which may be affected include respiration, feeding, migration, spawning, egg laying, incubation and emergence. Change in flow regime may also give one species a competitive advantage at the expense of other species.

6.2.1 Reduction in flow

Changes in flow regime cause hydraulic and morphological changes which affect the biota of streams through several modes of impact. Biological responses will vary according to the severity of the flow change and the particular system being considered. Figures 26 to 32 indicate the likely order of biological responses with increasing flow reduction.

Fig 26: Effect of change of flow on physical conditions affecting biological communities (adapted from Biggs 1982).



6.2.1.1 Reduction in volume

Reduction in volume in a river reduces its capacity to dilute and breakdown (assimilate) inputs of nutrients, toxic substances and organic material (Biggs, 1981). Therefore reductions in flow upstream of inputs of these substances lead to their increased concentrations.

Nutrient enrichment

Increased concentrations of nutrients (phosphorus and nitrogen) may stimulate the growth of plants (periphyton and macrophytes) (Horner et al., 1983; Bothwell, 1988). Where nutrient enrichment is long term, disproportionate stimulation of some periphyton species may lead to a reduction in periphyton species diversity.

Mild increase of plant biomass may also increase the biomass of invertebrates which graze these plants (Biggs and Lowe, 1994; Steinman, 1996). For example, where filamentous algae proliferate, snails and sap sucking invertebrates which feed on the algae will be advantaged. However, more severe periphyton growth may reduce diversity of invertebrate species by smothering their habitat (Quinn and Hickey, 1990). Where periphyton species are reduced by competition, specialised grazing invertebrates may lose food sources.

Organic enrichment

Mild increases in concentrations of organic material may increase invertebrate and fish biomass by increasing plant growth and invertebrate food availability (Perrin et al. 1987). However more severe organic enrichment can cause oxygen depletions as microbial breakdown consumes dissolved oxygen (Hynes, 1970) . This can lead first to a reduction in invertebrate and fish diversity and reduced biomass.

Organic enrichment may also reduce invertebrate habitat by smothering. This may lead to reduced invertebrate diversity in mild cases and reduced invertebrate biomass with more severe enrichment.

Toxic chemical concentrations

Reduced volume will also lead to increased concentration of toxic chemicals where inputs of these are downstream from abstraction points. Depending on the toxicant, this can reduce diversity and total biomass of plants or invertebrates and fish.

Reduction in dissolved oxygen

Adequate dissolved oxygen (DO) content of water is critical to stream health (Alabaster and Lloyd, 1980). Near-saturation values (8 to 10 grams per cubic metre) are optimal. DO can be lowered by flow reductions in two ways.

Downstream "sag"

At existing low flows the DO may exhibit a "sag", caused by the inflow of organic waste from point sources. That is, as the waste is carried downstream from the discharge site it is oxidised by bacteria that consume dissolved oxygen. Particularly in sluggish streams, the rate of consumption of this oxygen tends to be greater than the natural rate of oxygen replenishment from the atmosphere ("re-aeration"). As a result the stream DO is gradually depressed—typically reaching a minimum over a kilometre downstream of the source. After reaching this minimum, if there are no further sources, the rate of bacterial consumption decreases and re-aeration tends to pull the DO up back toward saturation (McBride and Rutherford, 1983).

Flow reductions affect the sag by decreasing the dilution of the point source. Flow reductions tend to *increase* re-aeration rates, but not to the extent of fully compensating for the effect of decreased dilutions. As a result the "sag" tends to be more severe, and located closer to the point source (McBride and Rutherford, 1983).

Diurnal variations

When there is an abundance of plant biomass DO problems may arise because aquatic plant metabolism causes diurnal DO variations. Plants respire (i.e. consume) oxygen continuously, but only produce it (via photosynthesis) during daylight. As a result the DO can vary substantially over a 24-hour period, being minimal at dawn and at a peak toward dusk. The only ameliorating factor is re-aeration. Consequently, diurnal DO variations are maximal in deep, sluggish streams with heavy plant growth. DO variations can be substantial, e.g. from 50 percent saturation to 120 percent saturation.

Flow reductions tend to exacerbate DO variations. That is, the rates of respiration/ photosynthesis per unit volume of stream water are increased, and the increase in re-aeration rate is not sufficient to overcome their effect.

Reduction in oxygen concentrations due to plant respiration may reduce the number of invertebrate species present. More tolerant invertebrates are likely to proliferate in these conditions (Biggs, 1981).

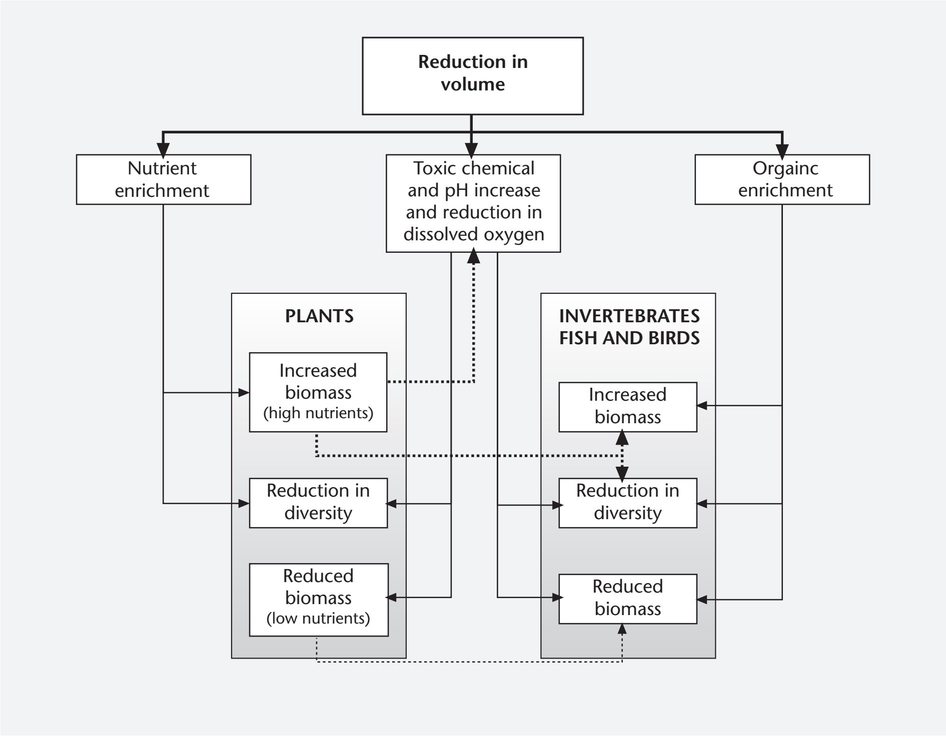
Increase in pH and ammoniacal nitrogen

The main concern with pH in stream low flow is its effect on the toxicity of ammoniacal nitrogen. This form of nitrogen, which is present in high concentrations in many agricultural wastes, has two components: non-ionised ammonia and ammonium ion. The former is much more toxic to aquatic life. The proportion of ammoniacal nitrogen (sometimes called "total ammonia") that is in the non-ionised form increases as pH and temperature increase. Accordingly, a given ammoniacal nitrogen concentration is much less toxic in cool acidic water than it is in warm alkaline water; pH tends to be less variable in well-buffered waters.

Stream pH can vary diurnally, however, and also because of plant metabolism (Biggs, 1982). Photosynthesis causes quite rapid shifts in the carbonate equilibria in water, increasing pH toward dusk.

As noted above, flow reductions exacerbate the diurnal DO variation, so that pH variations increase also. In the presence of substantial ammoniacal nitrogen concentrations (say half a part per million) ammonia guidelines for the protection of aquatic life may be exceeded for short periods.

Fig 27: Schematic diagram of biological response to reduction in volume (adapted from Biggs, 1981).



NB.The increasing intensity of shading indicates the likely order of biological responses with increasing flow reduction.

6.2.1.2 Reduction in velocity

Change of habitat suitability

Hydraulic conditions affect the abundance and composition of biota in a river reach. Some species have definite preferences for depth and water velocity, and this may change through their life cycles (Collier, 1994). Reductions in velocity can therefore improve or degrade the available habitat depending on the preferences of the individual species and life stages considered.

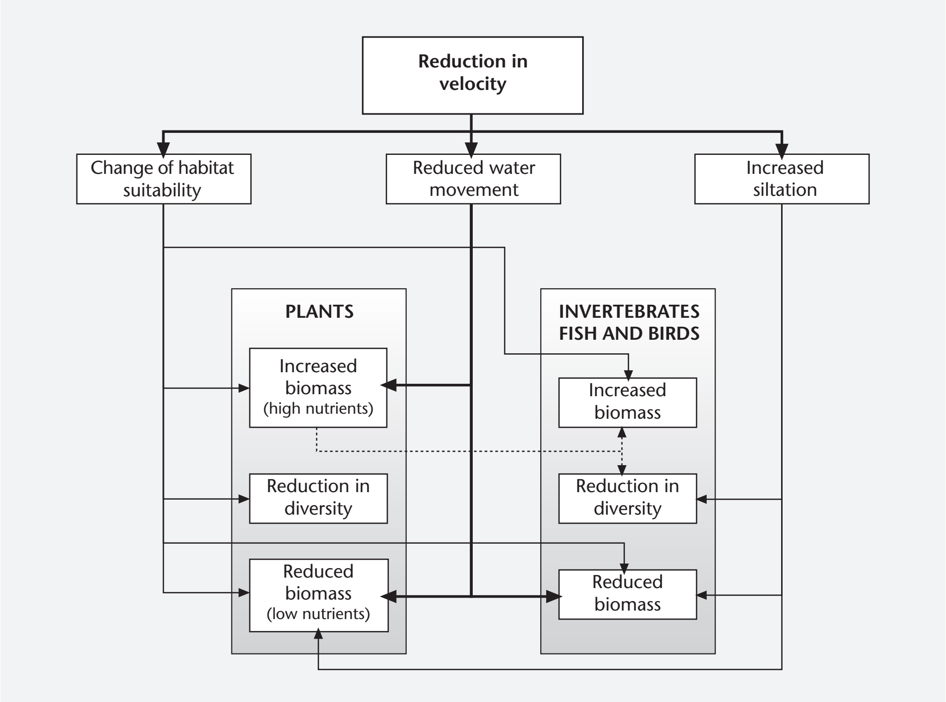
Reduced velocity reduces bed movement and shear forces at the surface of bed material. Where nutrient conditions are favourable, this may lead to an increase in production of plant biomass as loss of biomass through sloughing (shear forces) and scouring (moving substrates) is reduced. A mild increase in plant growth may increase invertebrate and fish biomass. Prolonged periods without physical disturbance of periphyton, however, may reduce invertebrate diversity by smothering habitats, reducing dissolved oxygen, or reducing pH and increasing ammonia toxicity (Biggs, 1981).

Where nutrient concentrations in the water column are low, reduced velocities may reduce the total nutrients (flux) available to plants. This can reduce biomass of plants which leads to reductions in invertebrate and fish biomass. Where velocity reduction is significant it can reduce the flux of dissolved oxygen available to invertebrates and fish, to reducing biomass of both (Biggs, 1981).

Increased siltation

Increased deposition (siltation) though reduced velocity will smother plants, reducing their biomass, with flow-on effects to invertebrates and fish. Increased siltation can reduce invertebrates diversity by smothering habitats of some species, and in severe cases significantly reduce biomass of invertebrates and fish.

Fig 28: Schematic diagram of biological response to reduction in velocity (adapted from Biggs, 1981)



NB. The increasing intensity of shading indicates the likely order of biological responses with increasing flow reduction. The dashed line represents secondary effects flowing from changes in the plant community.

6.2.1.3 Reduction in depth

Change of habitat suitability

Some species have different preferences for depth (Jowett et al. 1991, Jowett and Richardson, 1995), so reductions in depth can improve or degrade the available habitat depending on the preferences of the species considered.

Reduction in depth can affect the passage of fish from one part of the river to another. Passage up and down rivers at critical times is essential for the life cycle of many New Zealand fish species. Trout migrate to upstream spawning reaches in winter. Adult eels migrate from rivers to the sea to spawn. Inanga, a common native galaxii species, spawn in or near estuaries. The young fish are washed into the sea where they grow and subsequently return to the river as whitebait. Indeed, few of New Zealand's native fish reside in the river for their entire life (McDowall, 1990). Reductions in depth, particularly during migratory periods, can therefore affect the success of migration and can result in reduced abundance.

Reduction in depth may have different effects on different species of birds. Those species which feed in shallow water may be advantaged, gaining areas within which they are able to feed. However, reduced depths could adversely affect the feeding abilities of swimming and aerial feeders - shallow water making swimming impossible and in extreme cases, making it hazardous for diving birds. Depth reduction may also allow predators access to breeding sites, causing a reduction in breeding success and a decrease in population size.

Invertebrates will allow themselves to drift in response to non-optimal conditions in velocity and depth. The physical process of reducing depth (draw down), perhaps as a result of intermittent abstractions, may cause an increase in invertebrate drift.

Increased light penetration and temperature range

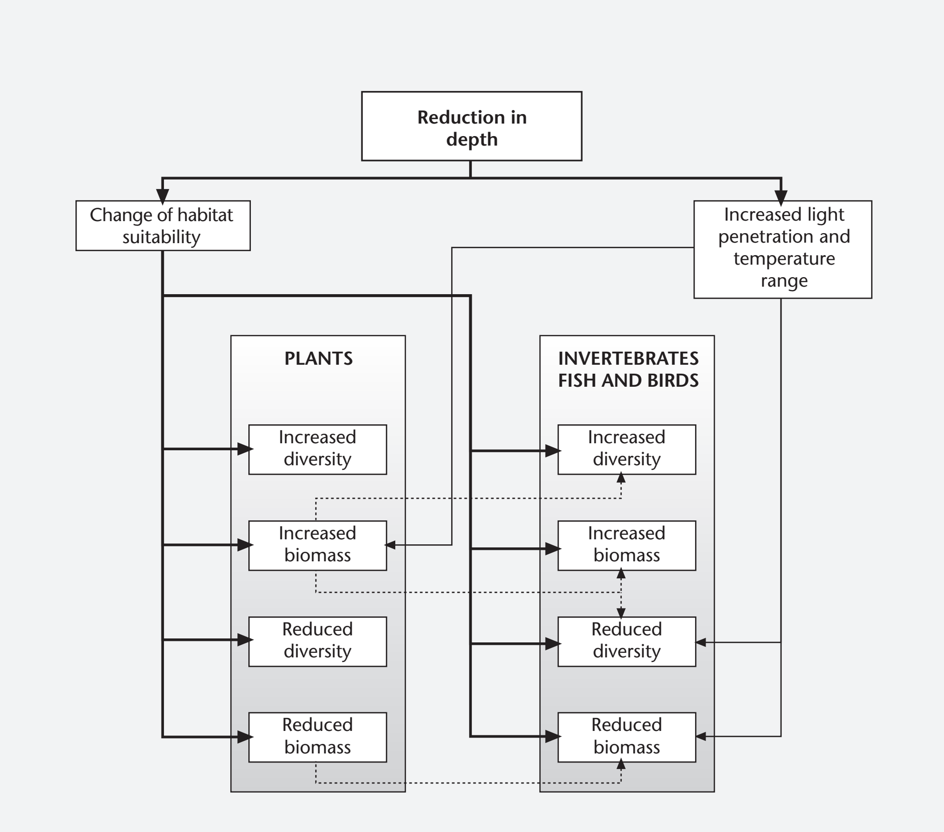
In mild cases, reduced depth may increase plant diversity and biomass by improving light penetration. However, severe reduction in depth will limit biomass as physical space becomes a limiting factor. In mild cases where waters are normally deep (e.g. > 0.5 m), these responses may result in increasing diversity and biomass of invertebrates and fish. A reduction in diversity and biomass of invertebrates and fish could be expected with large increases in plant biomass due to smothering habitats, reducing dissolved oxygen, or reducing pH and increasing ammonia toxicity.

Abstraction tends to increase the daily maximum temperature because as flow decreases so does the mean depth. For a given surface heat flux, the rate of change of temperature is inversely proportional to mean depth. Water temperature influences stream ecosystem structure and function (Allan, 1995) and there is considerable interest in predicting changes in water temperature and the resulting ecological impacts arising from activities such as abstraction and the removal of riparian vegetation (Dymond and Henderson, 1981; Dymond, 1983).

Several New Zealand native invertebrate and fish species favour cool water temperatures. For example studies have found that several species of Tricoptera (caddis flies) were less abundant at pastures sites than at headwater, native-bush sites probably because of temperature. Trout have definite upper temperature limits (Scott and Poynter, 1991, Quinn and Hickey, 1990 found that stonefly abundance declined markedly in New Zealand rivers once maximum summer water temperatures exceeded 19°C. In a laboratory study, Quinn et al. (1994) found that the lethal temperature for a range of common stream invertebrates varied from 22.6 to 32.4°C. Simons (1986) estimated that the upper temperature limit for the long-term survival of sensitive native species was less than 26°C. Richardson et al. (1994) found that smelt avoided the cooling-water plume below the Huntly power station once its temperature exceeded 26°C, and that inanga migration along the left bank past the station ceased once plume temperatures exceeded 27°C.

Increased temperature resulting from reduced depth may increase plant biomass in mild cases resulting in effects to invertebrates and fish. However, increased temperatures are expected to reduce invertebrate and fish species diversity if critical thresholds for less tolerant species are crossed. In severe cases, it may lead to a reduction in total invertebrate and fish biomass.

Fig 29: Schematic diagram of biological response to reduction in depth (adapted from Biggs, 1981)



NB. The increasing intensity of shading indicates the likely order of biological responses with increasing flow reduction. The dashed line represents secondary effects flowing from changes in the plant community.

6.2.1.4 Reduction in width

Reduction in habitat area

Where it is temporary, reduction in width (wetted portion of the channel) may lead to reduced diversity and reduced biomass of plants, as habitat is temporarily lost. Reduction in plant biomass could affect invertebrates and fish. Invertebrates and fish diversity and biomass may also be reduced by reduction in bed area, however change in habitat may increase diversity under these conditions. Populations of some species can often survive temporary drying by burrowing into sediments (e.g. chironomids and oligochaetes), by having desiccation-resistant eggs (e.g. some stoneflies) or by migrating to permanently wet areas (Biggs, 1981). Recolonisation of temporarily dry bed areas follows resumption of flow. Adjacent wet areas are important sources for mobile colonising organisms.

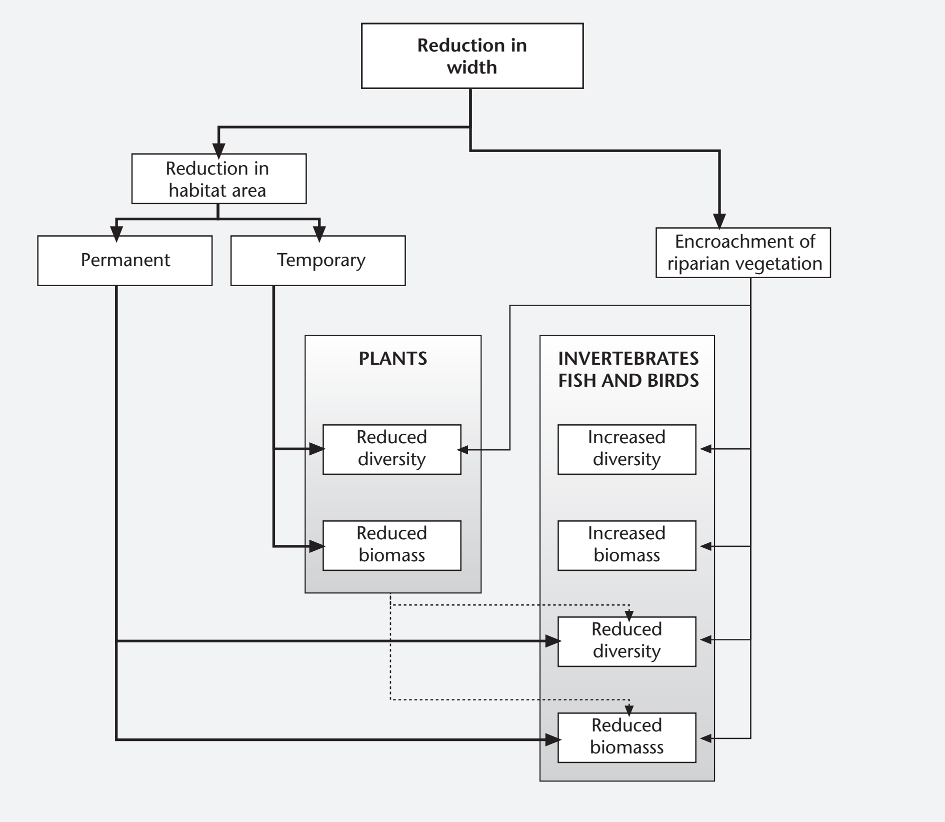
Encroachment of riparian vegetation

Complications arise when riparian vegetation encroaches into the wetted bed. This can increase terrestrial inputs of organic material such as leaves (food material for some invertebrates) and terrestrial invertebrates (food material for some fish), potentially resulting in increased biomass of invertebrates and fish. However increased shading of the wetted area may reduce light in the channel and reduce plant biomass (Biggs, 1981).

Riparian vegetation may encroach on to the stream channel if the channel bed is dewatered for prolonged periods. This may affect habitat conditions in the channel by shading. This vegetation and other organic matter such as animal faeces may also accumulate on the de-watered river bed and result in significant short-term organic nutrient inputs when higher flows return.

Increased riparian vegetation may provide more favourable breeding and feeding for some species, especially waterfowl. Riverbed specialist bird species, however, will be disadvantaged because increased riparian vegetation may result in an enclosed canopy, which is not favoured by some species. This is particularly the case for aerial feeders, which require open riverbeds over which to fly. In addition, any increase in vegetation within the riverbed makes it unsuitable for breeding of some riverbed specialists, and provides cover for potential predators of these species.

Fig 30: Schematic diagram of biological response to reduction in width (adapted from Biggs, 1981)



NB. The increasing intensity of shading indicates the likely order of biological responses with increasing flow reduction. The dashed line represents secondary effects flowing from changes in the plant community.

6.3 Reduction in frequency and magnitude of flood flows and constant base flows

Dams change flow regimes and may produce low flow conditions with similar biological responses to those described above. However, dams can also reduce flood flows due to their storage volume, increase flow constancy from controlled release rates and reduce sediment supply. The biological responses to these modes of impact are discussed below.

6.3.1 Flow constancy

Increased flow constancy can increase plant and animal biomass by reducing the physical disturbance to biota. However, some species will be adapted to the magnitude and frequency of flow changes in a natural flow regime and flow constancy may interfere with important biological processes. For example trout are thought to be encouraged to migrate upstream to spawn by small flood (spates).

Flow constancy may also allow excessive plant growth (periphyton in particular) which would naturally be controlled by physical disturbances (Biggs, 1982). This may increase food for invertebrates and increase invertebrate biomass but may reduce invertebrate diversity by smothering habitats (Armitage 1978, Biggs 1982).

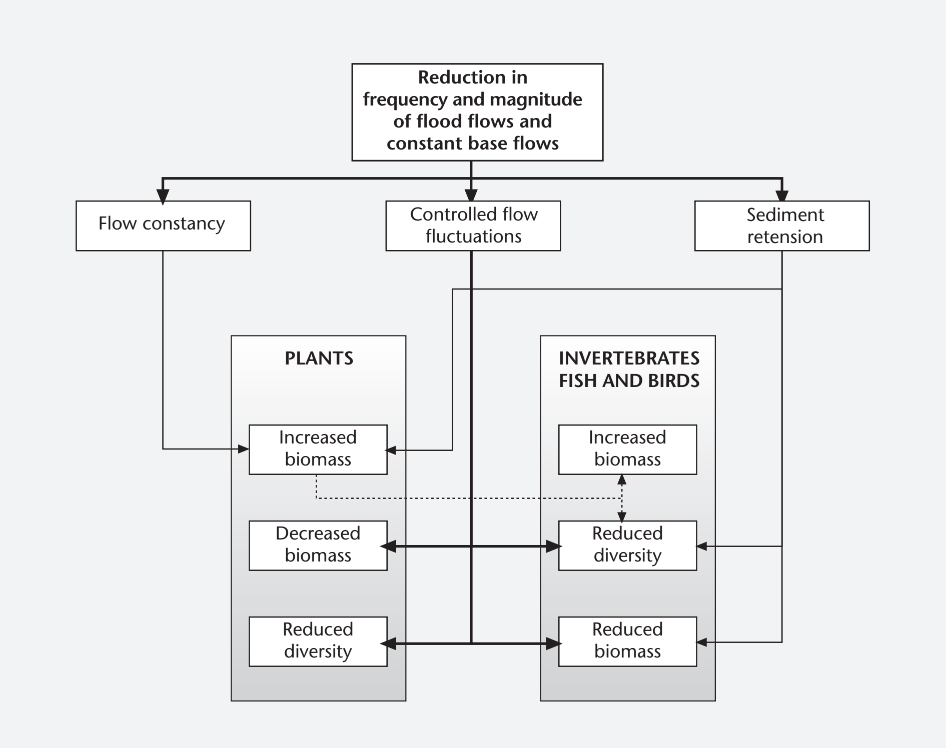
6.3.2 Sediment retention

Sediment retention by upstream dams and consequent increase in bed substrate stability though bed armouring can increase biomass of plants and animals by providing stable substrates and habitat (Biggs, 1982). Too much armouring, however, may reduce habitat for some invertebrates.

6.3.3 Controlled flow fluctuations

Controlled flow fluctuations and resultant velocity fluctuations can reduce diversity and biomass of plants and animals if fluctuations are abrupt and sufficiently large (Biggs and Close, 1989).

Fig 31: Schematic diagram of biological response to reduction in frequency and magnitude of flood flows and constant base flow (adapted from Biggs, 1981)



NB. The increasing intensity of shading indicates the likely order of biological responses with increasing flow reduction. The dashed line represents secondary effects flowing from changes in the plant community.

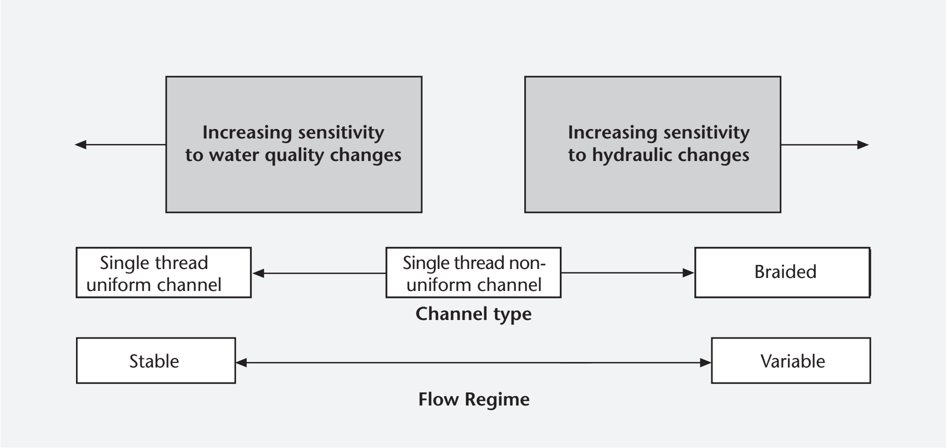
6.4 Sensitivity of the biological communities of different river types to reductions of flow

The biological communities of different river types have different sensitivity to the physical changes produced by reductions of flow. All the modes of impact which cause biological response to reductions in flow have the capacity to produce biological responses which may be judged to be adverse effects. However, different modes of impact become critical under different circumstances. Some generalisations about the likely limiting factors for biological communities can be made by considering river type.

Modes of impact can be separated into effects on the hydraulic conditions (depth, width and velocity) and effects on water quality (e.g. nutrient and dissolved oxygen concentrations, pH etc). Where total plant biomass is high, there are nutrient, organic matter and toxic contaminant inputs. When abstractive and waste assimilation uses of the water resource are combined, reductions in flow will tend to produce critical water quality changes for biota. High plant biomass is more likely where river flow regimes are stable, nutrient supply is high and channels have uniform cross-section and low water velocity.

Where biomass is relatively low and rivers have variable flow regimes, low nutrient supply and non-uniform channel cross-sections as well as hydraulic changes which cause changes in habitat quantity and suitability are likely to produce biological responses which may be judged to be adverse effects. These generalisations may not hold for all circumstances, and limiting key characteristics must be assessed case by case.

Fig 32: Sensitivity of biological community of different river types to reductions in flow



6.5 Ecological effects of change of river mouth opening regime

There are several important direct and indirect ways in which mouth closure can affect ecological values of rivers.

The primary effects are:

- interruption of fish passage in and out of rivers
- changes to the feeding and breeding habitat of birds.

Other potential effects are:

- changes in salinity
- deterioration in water quality through increased algal growth and accumulation of organic debris
- increased sedimentation
- reduced opportunities for recreational fishing due to either or both of the above.

6.5.1 Interruption of fish passage

River mouth closures will prevent the migration of fish species into and out of river mouths. Depending on the time of the year of closure, this may disrupt a crucial life stage of a species (McDowall, 1995) (see Chapter 5).

6.5.2 Changes to the feeding and breeding habitat of birds

6.5.2.1 Feeding

Whether a bird species is affected by a change of river mouth opening regime depends upon that species' main method of obtaining its food, and its preferred food. An increased frequency and duration of closure can lead to changes in the distribution of favourable feeding conditions for different species. River mouth closure changes the depth of the water within the estuary. Although aerial, diving and dabbling species may not be affected initially by increased water depth, those that feed by wading are immediately disadvantaged as the depth of water in which they can feed is determined by the length of their legs. Also, although shallow water may occur around the edges of the enlarged estuary, the depth profile may not be the same as that when the river mouth is open, and so the area of water suitable for feeding may be less than previously. Also, as the river backs up, shallow water areas tend to occur near tall vegetation. This is not favoured by species such as stilts, dotterels, godwits and oyster catchers, as the vegetation provides cover for potential predators of these species. Therefore, the first group of species to be affected by river mouth closure are those which obtain their food by wading or from along the margins of the water. The immediate response of these species is to move elsewhere in search of suitable feeding conditions.

Dabblers are the next group of birds to be affected by river mouth closure. Increased water depth may not affect their feeding initially, however, if these increase beyond the depth at which these species are able to obtain food from the bottom or from aquatic vegetation then these too may move elsewhere to feed, for example, onto adjacent farmland. Use of river mouths by dabbling ducks and swans for resting, however, may actually increase during periods of river mouth closure because the birds obtain greater protection from predators and disturbance.

Whether aerial feeders and divers are affected will depend upon the duration and timing of river mouth closure. As discussed elsewhere, a high proportion of our fish fauna requires access to and from the sea at some stage of their life. These fish are preyed upon by several species of birds, so if river mouth closes when juvenile fish should be entering the river from the sea, the number of prey available to such avian predators as terns and shags may be severely reduced, and the birds will move elsewhere to feed.

Moving elsewhere is the obvious response of birds when their food supply is reduced, but this should not be presumed to have no effect on bird populations. Population size in birds is influenced by mortality rates of individuals of different status (age and sex) and by reproductive rates. Birds forced to move because of river mouth closure may cause increased competition for food in the areas to which they emigrate. This in turn may result in increased mortality or reduced reproductive effort because fewer are able to attain a condition sufficient enough for them to breed.

6.5.2.2 Breeding

The egg-stage of the breeding cycle is the most vulnerable to increases in water depth and therefore to change in river mouth closure. Although non-flying young of species such as pied stilt and banded dotterel can swim, rising water levels probably result in increased mortality. The breeding season for estuarine bird species usually extends from August to December, so river mouth closure during this period could greatly reduce their breeding success. These effects are most likely to include loss of favoured nesting sites, loss of eggs, and loss of non-flying young. The most affected species would be those which prefer nesting on bare gravel close to the water’s edge.

6.5.3 Changes in salinity

Although prolonged closure may cause a reduction in salinity within impounded areas, this is unlikely to be a major problem for freshwater fish, as estuarine species are able to tolerate changes in salinity. It could affect marine species such as bivalves and barnacles if they were impounded behind the berm.

6.5.4 Deterioration in water quality

With the reduced flow and possibly greater accumulation of nutrients associated with mouth closure, there is a strong likelihood of prolific plant growth (e.g. *Enteromorpha* spp.) in the impounded area. In small rivers, this may be compounded by the decomposing of any marine debris, plus input of other organic material (e.g. macrophytes from weed cutting).

6.5.5 Increased sedimentation

Increased sedimentation may occur as estuaries are usually areas of deposition of sediments. Although high sediment loads are more associated with high flows, any suspended solids within the water column (whether from natural or man-induced sources) are liable to settle within the lower reaches of rivers and estuaries. Normally such sediment will be resuspended and flushed from the catchment during the next significant flood.

6.5.6 Reduced opportunities for recreational fishing

Recreational fisheries such as whitebaiting and salmon and kahawai fishing depend upon these species having access to rivers. Any prolific weed growth reduces opportunities for fishing by fouling gear (hooks and nets), and decomposition products such as hydrogen sulphide, may lead to fish avoiding such areas.

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7. Technical Assessment Methods for Biological Values

7.1 Tests for change in flow variability

Flow variability (i.e. the frequency, intensity and duration of flows) is important in the assessment of instream flow regimes, but has rarely been considered until recently. Damming, diversion and abstraction can all alter the natural pattern of flow variability. A highly variable flow can result in the loss of most biological activity in a river, whereas a fixed flow over long periods (many months to years) can result in certain communities dominating the ecosystem to the detriment of other components. A moderate frequency of flow changes helps to prevent the accumulation of excessive instream plant production and detritus, while allowing a diverse array of benthic invertebrates.

Recent research in New Zealand has shown that a reasonable measure of flow variability is the number of times per year flows exceed three times the long-term median flow (a variable called FRE_3) (Clausen and Biggs, 1996a). This measure incorporates a frequency and intensity component. Periphyton biomass (and also diversity) is generally high and invertebrate abundance low (but diversity quite high) where FRE_3 is $< 5\ y^{-1}$ (i.e. less than an event every 10 weeks). Invertebrate abundance is highest, diversity high and periphyton biomass moderate to low (but still sufficient as an invertebrate food source) where FRE_3 is 10-15 y^{-1} (i.e. an event every 3.5 to 5 weeks) (Clausen and Biggs 1997). Periphyton biomass and diversity, and invertebrate abundance and diversity are all generally low in rivers where $FRE_3 > 20\ y^{-1}$ (i.e. more than one event every 2.5 weeks). A significant change in the value of FRE_3 as a result of a proposed activity may therefore indicate the risk of a change in the biological community.

Although FRE_3 provides a guide, in some situations it may not apply very well. In regulated rivers downstream of dams, the supply of sediments is reduced and bed armouring occurs. This results in reduced bed sediment movement during high flows so a flow perturbation of FRE_3 may be insufficient to cause much removal or destruction of communities. Some research has suggested that an intensity of five times the median flow (or regulated low flow) may be a more appropriate criterion in such regulated rivers (Biggs and Close, 1989). The reduction in bed sediment supply may also result in morphological changes to the river channel. Expert assistance is recommended to assess the likelihood of this.

7.2 Minimum flow assessment methods for habitat

7.2.1 Historic methods

Many historic flow methods based on hydrological data have been used to define minimum flows. Three variants of these are described below.

7.2.1.1 Exceedance methods

These include flows such as the mean annual, 1 in 5-, 10- or 20-year 7-day (or some other duration) low flow or percentages of those, or a percentage exceedance flow (i.e. a minimum flow is defined as a flow that is equalled or exceeded for a proportion (e.g. 96 percent) of the time. The principles underlying this technique are very similar to those of the Tennant method but use naturally occurring low flows rather than mean flow to define minimum flow (Chaing, 1976).

7.2.1.2 Tennant method

Tennant (1976) recommended specific percentages of mean annual flow based on field observations of the wetted perimeter, cross-sectional area and velocity of North American rivers at a range of flows. The Tennant method (known in New Zealand as the Montana Method) was based on a study of cross-section data from 11 streams in Nebraska and Wyoming in the USA. The study found that stream width, water velocity and depth all increased more rapidly from zero flow to 10 percent of the mean flow, than at flows higher than 10 percent of the mean flow. Habitat for trout formed the basis for Tennant's assessment of minimum flow. He considered that an average depth of 0.3 m and velocity of 0.23 m/s, as provided by 10 percent of the mean flow, were lower limits for the well-being of trout, whereas an average depth of 0.46 m and velocity of 0.46 m/s, as provided by 30 percent of the mean flow were within the good to optimum range.

From these observations, he recommended that 60-100 percent of mean annual flow would provide optimum flows for most forms of aquatic life, 30 percent would provide good habitat, and that 10 percent was a minimum below which only short-term survival of aquatic life could be expected. Tennant also recommended periodic flushing flows of 200 percent of the mean annual flow.

Change in width, depth and velocity (as a proportion of mean flow) for two channel types (single thread uniform and single thread non-uniform) is shown as a function the percentage in mean flow on Figure 25. It can be seen that, in general the hydraulic conditions change at a high rate from zero to approximately 10 percent of the mean flow. However, this is variable and is dependant on the hydraulic parameter and geometry of the channel being considered.

Annual minimum flows in New Zealand rivers are, on average, 23 percent of the mean flow, but vary from 1 percent to 97 percent. The majority are between zero to 40 percent of the mean. A study of 136 New Zealand rivers found that, on average, the median flow (the flow which occurs most often and therefore a measure of the usual base flow) was 63 percent of the mean flow (Jowett and Duncan, 1990). Tennant's "base flow regime" is therefore about half the median flow in New Zealand rivers.

7.2.1.3 Modified Tennant method

Fraser (1978) suggested a modification of the Tennant method for New Zealand rivers as an interim measure only until a more defensible method was established. He recommended as an emergency "rule-of-thumb" that 100 percent of the mean flow for each month be considered "optimum", 75-99 percent "acceptable", 30-74 percent as "poor-fair", and 29 percent or less as "unacceptable". Fraser noted that this regime could reduce peak flood flows which may be important in maintaining the normal ecosystem in some rivers, and recommended that flushing flows be maintained for "optimum" and "acceptable" flow regimes.

The ecological effectiveness of using mean monthly flows has not been established in New Zealand. However, similar aquatic communities exist in rivers with opposite seasonal patterns of flow. This may indicate that the seasonal variation is not an important ecological factor. A modified Tennant method using mean monthly flows was used to set minimum flows for the Rakaia River.

7.2.2 Hydraulic methods

Hydraulic methods usually consider river width or wetted perimeter. Hydraulic parameters such as width, wetted perimeter and velocity increase with increased flow. This increase is non-linear and a point is generally reached where the rate of increase in the value of a parameter reduces rapidly. This point is called the point of inflection and marks the point beyond which increased flow will have a diminishing effect on the hydraulic parameter being considered. Water velocity is not usually considered in hydraulic methods, possibly because it shows less clearly defined inflection points.

The wetted perimeter approach provides information on the effects of different flows on the area of wetted river channel which is assumed to provide habitat for aquatic life. For both uniform and non uniform channel cross-sections, there is a rapid increase in wetted perimeter from zero discharge to the discharge at an inflection point, beyond which additional flow results in only minor increases in wetted perimeter. Minimum flows are set near the inflection point of the wetted perimeter versus discharge curve. Braided channels and some gravel bed channels have very flat cross-sections and ill-defined banks. These channel types do not show a clear inflection point.

Fifteen or more cross-sections should be randomly chosen for the wetted perimeter method. Cross-sections are best placed in riffles and runs because these are areas of the stream most seriously affected by reduced discharges.

This technique may be unsatisfactory for identifying minimum flows in uniform steep-banked channels. This is because a very small flow may just cover the bed of the channel between the banks. The shallow depth and low velocity at this point of inflection may be unsuitable for many biota. However, in rivers with non-uniform channel cross-sections, the irregular channel shape will tend to produce a variety of channel depths across the cross-section when the inflection point is reached.

Hydraulic methods such as wetted perimeter methods evolved in the US where dry river channels as a result of upstream water use is not uncommon. The philosophy behind these methods is therefore to maintain water in the channel without considering habitat requirements in terms of depth and velocity, while maximising abstractive use.

7.2.3 Habitat methods

Habitat is an encompassing term used to describe the physical surroundings of plants and animals. Some aquatic habitat features, such as depth and velocity, are directly related to flow, whereas others describe the river and surroundings.

Habitat methods are a natural extension of hydraulic methods. The difference is that the assessment of flow requirements is based on hydraulic conditions that meet specific biological requirements rather than the hydraulic parameters themselves. Hydraulic models predict water depth and velocity throughout a reach. These are then compared with habitat suitability criteria to determine the area of suitable habitat for the target aquatic species. When this is done for a range of flows (flow increments), it is possible to see how the area of suitable habitat changes with flow.

7.2.3.1 Habitat suitability

Instream habitat usually refers to the physical habitat water velocity, depth, substrate, and perhaps cover. Usually, animals are most abundant where the habitat quality is best, in lesser numbers where the habitat is poor, and absent from totally unsuitable habitat. Many aquatic species are commonly found in similar hydraulic conditions in a wide range of rivers. If the characteristic habitat occupied by a species is surveyed, it is possible to determine the relative quality of the different habitats from the abundance of animals in them. Preference curves are the measured variation in the frequency of animals with change in depth, velocity and substrate. Sampling and analysis techniques have been developed that allow preference curves to be developed easily and quickly. The locations of animals are found by electro-fishing for small benthic fish, bank observation for large trout and birds, or Surber sampling for invertebrates.

Habitat suitability curves for a particular section of river show the variation in the total quantity of habitat with change in flow for a particular species. Habitat suitability can vary from zero (unsuitable) to one (optimum). Providing preference curves for a species (or life stage of a species) has been determined, it is possible to quantify the area of suitable habitat available within a river for that species. This area is termed the useable area or weighted useable area (WUA).

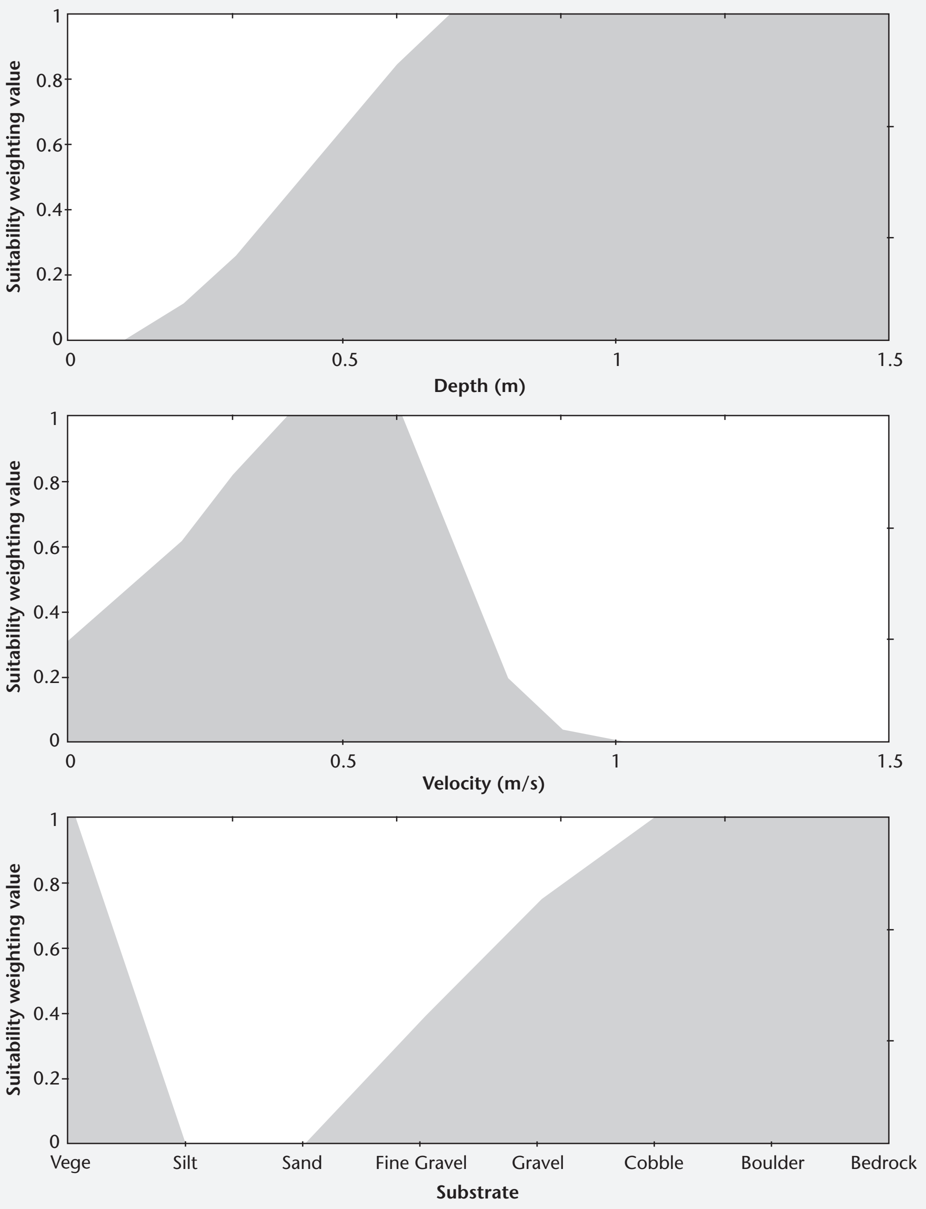
Preference curves have been developed for a wide range of species in New Zealand. These are listed in Table 6 below.

Table 6 Habitat suitability curves available for New Zealand aquatic species

Sport Fish	Native fish
Brown trout fry to 15 cm Brown trout yearling Rainbow trout adult Brown trout spawning Brown trout adult Rainbow trout fry Rainbow trout fingerling Rainbow trout adult Food producing (habitat suitability)	Koaro Common river Galaxii Longfin eel Shortfin eel Upland bully Common bully Crans bully Redfin bully Bluegill bully Torrentfish Lamprey (juv) Inanga Common smelt Dwarf Galaxii
Invertebrates	**Birds**
Naididae (worms) Zelandoperla (stonefly) Deleatidium (mayfly) Pycnocentrodes (stony cased caddis) Olinga feredayi (horny cased caddis) Aoteapsyche (net spinning caddis) Hydrobiosidae (free living caddis) Coloburiscus humeralis (mayfly) Nesameletus (mayfly) Maoridiamesa (Diptera) Aphrophila (Diptera)	Wading bird general Blue duck adult feeding habitat Blue duckling feeding habitat

Collier (1993, 1994a, 1994b), Jowett (1990)

Fig 33: Example of a set of suitability curves for adult brown trout drift feeding habitat derived from measurements at about 400 trout feeding locations. (source: Jowett, 1992)



7.2.3.2 Habitat retention method

Habitat retention methods to the many approaches. Nehring (1979) described a method used by the Colorado Division of Wildlife in which minimum flow recommendations are based on retention of hydraulic characteristics in various habitat types (riffles, runs and pools). These criteria consist of average depth, average velocity and wetted perimeter, and instream flow recommendations are set when two or more criteria for the appropriate stream size and habitat are met.

More than forty years ago, McKinley used habitat requirements for salmon spawning in North America (McKinley, 1957). Osborn (1982) developed another habitat retention approach for assessing minimum flows for salmon in North America. He calculated the discharge at which maximum spawning area became available using velocity and depth criteria determined from existing information, and from calculations of bank-full discharge (similar to procedures in IFIM). The latter calculation required a single field trip to obtain measurements of channel geometry.

7.2.3.3 Instream flow incremental methodology (IFIM)

Once habitat suitability curves or criteria are defined, they can be applied to habitat survey data and the amount of suitable habitat calculated for a range of flows (flow increments). This is the basis of the instream flow incremental methodology (IFIM) (Jowett, 1989).

A fundamental criticism of IFIM has been that, although it seemed reasonable to assess instream flow needs on the basis of the amount of suitable habitat, there was no evidence that there was any correlation between species abundance and the amount of suitable habitat (Scott, 1987). This is not an unreasonable criticism; assessments of habitat should be considered to represent the potential of a river to maintain a population of the target species. Having said this, studies have found correlation between habitat availability and animal abundance for many species of benthic invertebrates and fishes.

It is also necessary to consider all the requirements for a species' continued survival. For example, the primary requirements for salmonids are both space and food. Assessing instream flow needs for a river must therefore consider salmonid space and food production requirements. Requirements for reproduction (spawning) must also be considered in river reaches which are used for this.

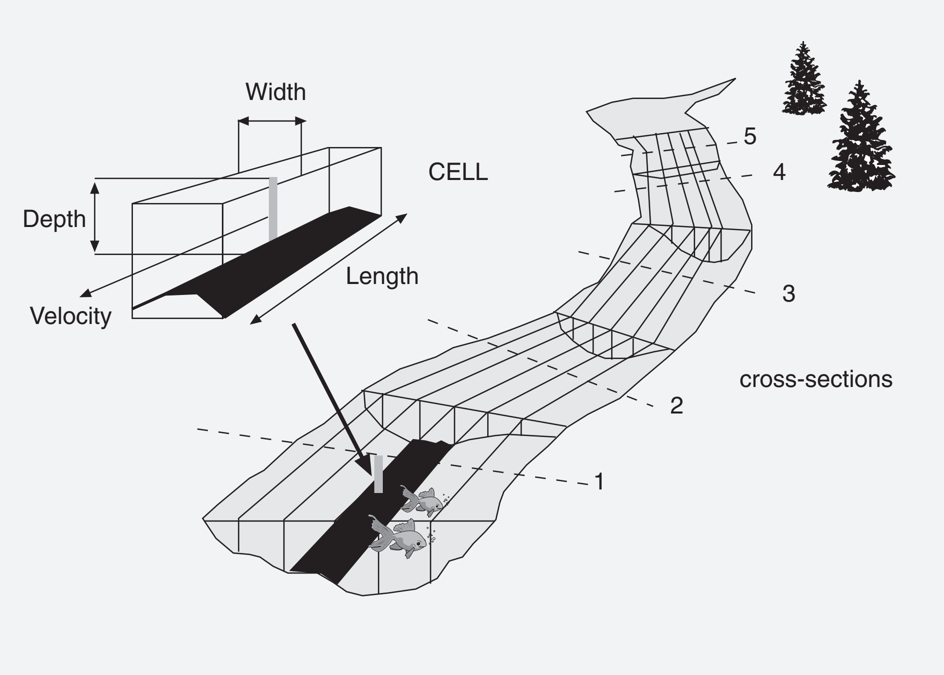
7.2.3.4 Hydraulic modelling and prediction of habitat suitability

The standard step method, used to model non-uniform steady flow in natural rivers, is well established in engineering practice. This method is based on the principle of energy conservation and uses the flow, slope, hydraulic roughness, and the hydraulic properties of the cross-sections to calculate the longitudinal flow profile. An important assumption in the method is that the distance between cross-sections must be short enough that the hydraulic properties of the cross-sections approximate the hydraulic properties and slope between them. This means that cross-sections should be located sufficiently close that the cross-section area increases or decreases uniformly between cross-sections and that the change in slope is kept to a minimum. In practice this means decreasing cross-section spacing at the heads and tails of riffles, where water slopes and cross-section areas change rapidly, and increasing the spacing when the hydraulic conditions are uniform. This sampling procedure is consistent with those used to sample instream physical habitat.

The hydraulic roughness (Manning's n) is determined from field data on discharge, cross-section area, hydraulic radius, and slope. Manning's n can vary with flow in an unpredictable manner (Hicks and Mason, 1991), and this limits the range of flows for which the roughness calibration is valid.

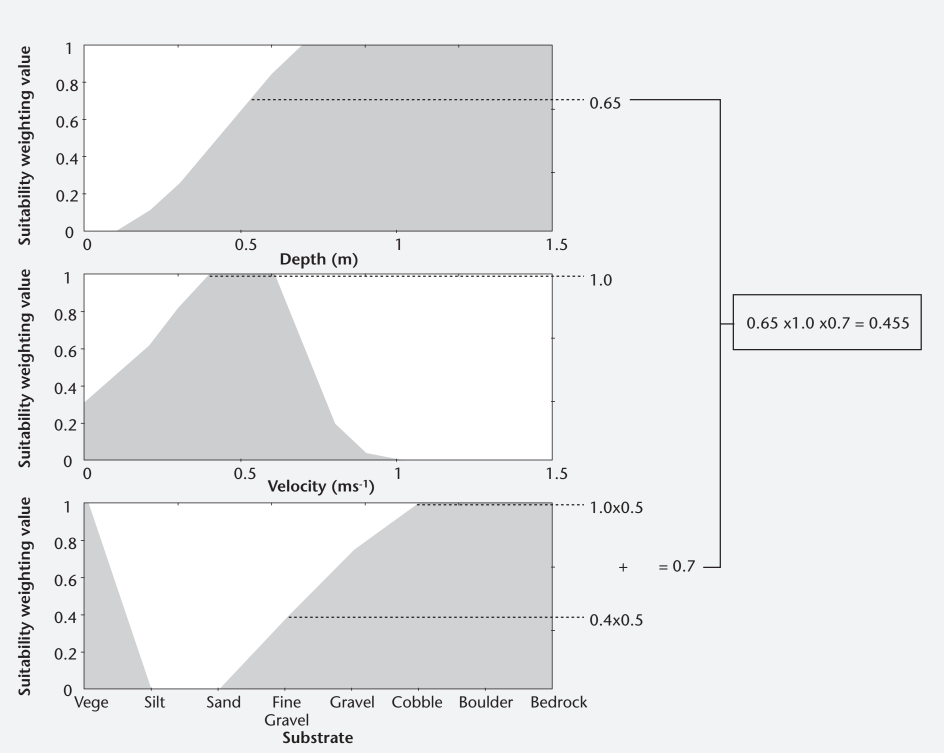
The distribution of water velocities across a cross-section can be calculated from its conveyance once the water level and flow are known. Each velocity can be adjusted for site-specific features, such as an upstream obstruction which might cause a reduction in velocity or a current on a bend increasing local velocities. Each measurement point represents a cell of the total river area (Figure 34) for which the suitability of the velocity, depth, and substrate is evaluated on a scale of 0 (unsuitable) to 1 (optimum).

Fig 34: Instream habitat modelling of a river reach showing cross-sections and cells (from Jowett, 1992)



The point suitability is multiplied by the plan area of the cell it represents and summed over the reach to give the weighted useable area (WUA). An example of calculating point suitability is shown on Figure 35. Once a hydraulic model of the reach is derived, water velocities and depths can be predicted for any flow and the amount of suitable habitat at that flow, evaluated. The computer programme RHYHABSIM combines hydraulic simulation and evaluation of habitat suitability.

Fig 35: Calculation of point suitability for a point with 0.5 ms^{-1} velocity, 0.5m depth, and a substrate of 50% boulders and 50% fine gravel. (source: Jowett, 1992)



7.2.3.5 Habitat mapping

Until recently, applications of IFIM in New Zealand have involved surveying and hydraulically modelling habitat across a series of contiguous cross-sections over a range of flows in representative reaches of river.

An alternative approach that requires less knowledge of hydraulic modelling is mesohabitat typing or habitat mapping. This approach better represents the physical habitat in the river over which the survey is intended to apply. Mesohabitat typing first requires that habitat is mapped over the segment of river under study so that the proportions of the different habitats of interest (e.g. pool, riffle, run, etc) can be calculated. Next, several cross-sections are chosen to represent each of the habitat types. At each cross-section, depths, mean column velocities, and substrate composition and recorded at approximately 0.5-1 m intervals, or with enough frequency to characterise the changes in depth and velocity across the section, as for hydraulic modelling. Flow and water level is recorded for each cross-section and repeated at two or more other flows to establish a stage-discharge relationship. Water velocities and depths over each cross-section can then be predicted for a range of flows, using the stage-discharge relationships and channel geometry. This prediction is usually more accurate than predictions made by water surface profile modelling. The area of suitable habitat (weighted useable area, WUA) can be calculated for each species of interest. The WUA at each cross-section is multiplied by the proportion of the total river length that each cross-section represents. The total WUA is then the sum WUA of all the cross-sections.

The computer programme RHYHABSIM has been extended to evaluate habitat surveys based on habitat modelling and includes useful tools for the derivation and comparison of rating curves at cross-sections.

7.2.4 Regional methods

Regional methods can be applied for a range of purposes, such as assessing physical habitat and water quality. To date, most of the use of regional methods in New Zealand have been for habitat purposes, but there has been at least one situation where a regional approach was used for water quality assessment. This water-quality approach is discussed in the case studies sections at the end of this volume. The discussion below focuses on regional *habitat* methods.

Regional methods are a recent advance on habitat methods. Instream flow requirements for food production and habitat depend primarily on the depth and velocity of the flowing water. These physical characteristics are in turn controlled by the morphological characteristics of the river (i.e. its width, mean depth, and slope). Thus, the amount of suitable instream habitat is related to these. Studies of rivers which are representative of regional river morphology can establish the quantity of habitat which is available for a target species at naturally occurring low flows. These evaluations must take into account the space requirements of the target species as well as the requirements for food production.

Weighted useable areas can be calculated for rivers and the values ranked to define habitat guidelines. In studies in the Wellington and Taranaki regions, WUA for 63 New Zealand rivers were used to rank rivers in terms of habitat for trout (Jowett, 1993a, 1993b). The rivers with the lowest amounts of habitat represent “poor” quality and those with the highest amount represent “high” quality. A habitat guideline was based on the percentage of rivers of higher or lower quality.

Relationships between habitat quality and water velocities and depths are the basis of the IFIM methodology. There are therefore several significant relationships between habitat and morphological characteristics. For instance, in the Wellington study the amount of adult brown trout habitat at low flow was positively related to the average depth, the mean annual low flow, and the mean flow. This is because adult trout show a preference for deeper water and the rivers with higher flows were deeper. Food producing habitat at median flow was positively related the average water velocity; benthic abundance is highest in high velocity water (Jowett, 1993a).

The Wellington study suggested that trout habitat should be maintained at a level equivalent to that exceeded by 85 percent of the national survey rivers at their mean annual low flow. In effect this is the Instream Management Objective for a targeted species (i.e. trout).

Retention of a minimum amount of useable habitat could result in large changes in the appearance of larger rivers. To prevent this, a second guideline, that of retaining a proportion of the existing habitat was suggested. A guideline of one-third loss (i.e. retention of two-thirds) of the existing habitat at naturally occurring low flows was suggested. No methodology exists for selection of a percentage of loss of “natural” habitat which would be considered acceptable. The suggested level of maximum percentage loss is therefore arbitrary.

Stepwise multiple regression was used to determine relationships between the minimum flows which met the suggested level of protection and river and catchment characteristics. Mathematical formulae were developed to calculate the minimum flow which maintains minimum habitats limits but limits the amount of habitat reduction to one third of that occurring at mean annual low flow. The formulae calculate a minimum flow for rivers in the study region as a percentage of the mean annual low flow, based on their mean annual low flows. Formulae in the Wellington and Taranaki studies are based on Instream Management Objectives for brown trout “criteria”. Formulae to derive minimum flows to maintain instream values for native fish and benthic invertebrates could be developed in a similar manner.

The regional approach is not designed to take account of water quality factors, such as increased algal growth, temperature and increases in concentrations of toxicants. Different assessment methods are needed to take account of these factors.

Regional methods are included as worked examples in Chapter 12.

7.3 Conceptual differences between minimum flow assessment methods for habitat

The following sections explain the conceptual differences between the different assessment methods and the suitability of applying them to meet management goals.

7.3.1 Historic flow methods

Historic methods are easy to apply because they are based on simple hydrological calculations. Factors like food, habitat, water quality, and temperature are not considered explicitly, but are assumed to be satisfactorily provided for because the aquatic species have survived such conditions in the past. These methods attempt to produce a "low risk" approach to an minimum flows by specifying flows that are in the historic range. The methods also provide some choice of the level of protection in terms of flow. However, flow acts as a surrogate for biological response and cannot be quantified biologically.

7.3.1.1 Exceedance flows

Use of an exceedance flow (e.g. annual, 5-year or 10-year 7-day low flow) will tend to preserve the status quo. The level of protection given by these methods is clearly associated with the recurrence of the minimum flow under natural conditions. That is, there is a higher level of protection to the biological community if the minimum flow is the same as a frequently occurring natural low flow. The choice of exceedance period should therefore reflect the significance of the biological community at risk, with communities of higher significance being afforded greater protection by setting more frequently occurring natural low flows as minimum flows.

7.3.1.2 Tennant methods

The Tennant and modified Tennant methods also attempt to maintain the status quo. The assumption that a proportion of the mean flow will maintain the instream environment is reasonable and the use of these methods is well established. The modified Tennant method offers a range of minimum flows with a descriptive measure of their acceptability. This offers some ability to consider the significance of the biological community at risk and level of environmental protection offered. For the same aquatic community, small streams will be more "at risk" than large streams, because velocity and depth are already relatively low.

7.3.2 Hydraulic methods

The aim of hydraulic methods is to describe how "full" the river channel is for given flows. It is assumed that a "full" channel will maintain the food-producing capacity of the river. If the inflection point method is used as the flow requirement, the resulting water depth, velocity, and ecological response will depend on channel geometry. For example, in uniform channels only a small and shallow flow is required to maintain a water across the full stream width. Under such conditions, the water depth and velocity may be unsuitable for many species. However, in many non-uniform channels, the water depth and velocity will be characteristic of those at natural flow, thus retaining both the "character" and ecology of the natural system.

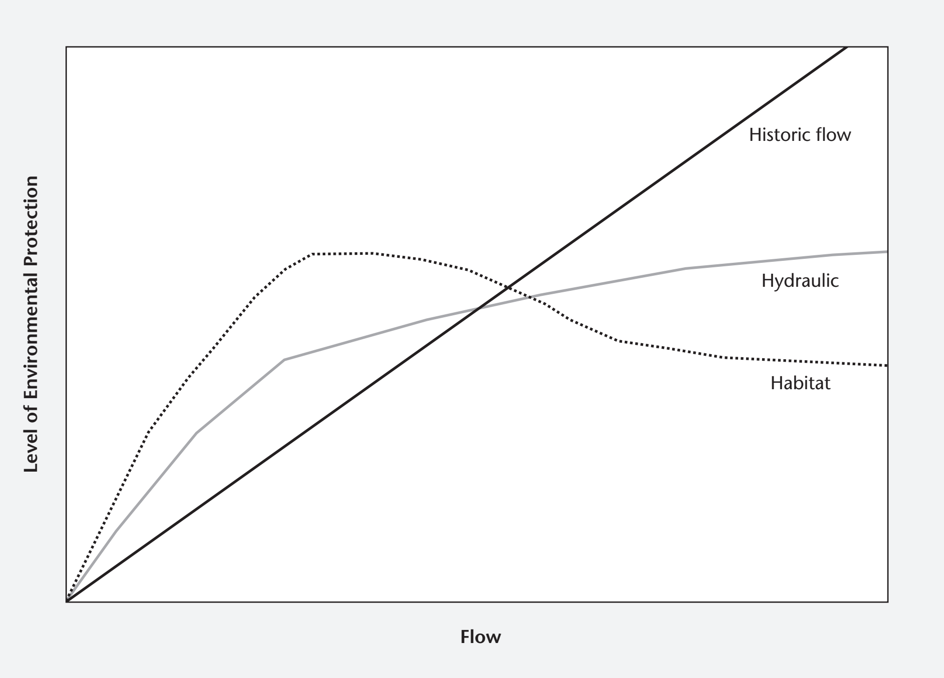
7.3.3 Habitat methods

The ecological goal of habitat methods is to provide or retain a suitable physical environment for the aquatic organisms that live in a river. With the focus of habitat methods on "target" species, there is a risk of failing to consider other essential components of a stream ecosystem. The selection of appropriate habitat suitability curves and consideration of other factors, such as food, temperature, and water quality is crucial. The key to successful minimum flow recommendations is to provide sufficient habitat for the maintenance of all life stages of the target species and to consider the requirements of the stream ecosystem as a whole (Jowett, 1996).

Habitat methods aim to preserve, or even improve, habitat, in terms of depth and velocity, rather than river "character". For example, a swift flowing river may contain large areas of deep, high velocity water that are not utilised by most aquatic species. A minimum flow based on habitat would suggest that the area of suitable habitat could be increased by reducing flows so that water velocities and depths were in the range of those preferred by a "target" species. This would result in a loss of the high velocity areas that lend "character" to a river. Flow assessments based on habitat tend to reduce rivers to a common denominator the habitat used by the "target" species (Jowett, 1996).

Habitat methods provide the most flexible approach to minimum flow assessments, but can be difficult to apply and interpret. Because of this, the outcome depends critically on how the method is applied: what species or uses are considered and what suitability curves are used. When using habitat methods, there are more ways of determining flow requirements than in either historic flow or hydraulic methods. The relationship between flow and the amount of suitable habitat is usually non-linear (Figure 36). Flows can be set so that they maintain optimum levels of fish habitat, retain a percentage of habitat at average or median flow, or set so that they provide a minimum amount of habitat. Flows can also be set at the point of inflection in the habitat/flow relationship. This is possibly the most common method of assessing minimum flow requirements using habitat methods. While there is no percentage or absolute value associated with this level of protection, it is a point of diminishing return where proportionally more habitat is lost with decreasing flow than is gained with increasing flow. Habitat methods are therefore useful for investigating and presenting the relative levels of protection offered by different minimum flow options.

Fig 36: Relationships between flow and the level of environmental protection offered by the different biological assessment methods for a hypothetical river



The level of environmental protection is measured in terms of the surrogate measures for biological response: flow for historic flow methods, wetted perimeter for hydraulic methods, and weighted useable area for habitat methods. (Source: Jowett, 1996).

Habitat-based methods differ from both historic and hydraulic methods in that they make no *a priori* assumptions about the state of the natural ecosystem. Historic and hydraulic methods assume that lower than natural flows will degrade the stream ecosystem, whereas habitat methods accept the possibility that a natural ecosystem, or at least some particularly valued target species, could be enhanced by other than naturally occurring flows.

Table 7 Levels of protection for different biological assessment methods

Biological assessment method	Assumed relationship between level of protection and flow	Level of protection specified by:	Examples of increasing levels of protection
Historic methods • Exceedance	Linear increase with flow	Exceedance flow	10 year, 5 year, Mean annual low flow
• Tennant	Linear increase with flow	% of mean flow	10% of mean flow 30% of mean flow
Hydraulic methods	Non linear increase with increasing flow	Hydraulic parameters	Increasing percentage retention of hydraulic parameter values
Habitat methods	Optimum conditions at a given flow Reducing protection for flows greater than or less than optimum	Habitat quantity	Minimum habitat Inflection points Optimum

7.3.4 Levels of environmental protection

The use of surrogate measures for biological response means that the level of environmental protection offered by biological assessment methods does not necessarily increase linearly with minimum flow. Historic flow methods assume that the biological response, and hence level of protection, is directly related to flow, with the level of protection increasing with flow.

Hydraulic methods assume that biological response is related to a hydraulic parameter such as wetted perimeter. Hydraulic parameters have a non-linear relationship with flow which is a function of channel geometry. Hydraulic methods therefore assume that environmental protection increases with increasing flow but that this relationship exhibits the law of diminishing returns.

Habitat methods have a non-linear relationship with flow which is a function of channel geometry and preferred habitat of the target species. Habitat methods therefore assume that environmental protection for the target species will be optimised at some flow and that increased or decreased flows will reduce the level of environmental protection.

7.4 Water quality assessment methods

Water quality methods seek to estimate explicitly the change in water quality parameters with change in flow. In general there are well established standards for water quality parameters, and water quality assessments seek to calculate flow thresholds below which a known biological responses would be anticipated. Water quality assessment methods therefore derive minimum flows below which a water quality standard would be breached.

7.4.1 Temperature

Abstraction tends to increase the daily maximum temperature because as flow decreases so does the mean depth and for a given surface heat flux, the rate of change of temperature is inversely proportional to mean depth. Because of the complexity of the problem, empirical studies have been unable to quantify precisely the effects of abstraction on water temperature but some success has been achieved using computer models.

Hockey et al. (1982) modelled the effects of abstraction in the Hurunui River, Canterbury (low flow 20-50 m^3 s^{-1}) and predicted that during summer the daily maximum water temperature would increase by approximately 0.1°C for every 1 m^3 s^{-} drop in flow, to reach a maximum of 25-26 °C at extreme low flows of about 10 m^3 s^{-1}. Dymond and Henderson (1981) tested a heat balance model in the much smaller Stony River, Taranaki (summer flow 3 m^3 s^{-1}) and predicted that an abstraction of 1 m^3 s^{-1} would increase maximum temperatures by 3°C. In each of these studies riparian shading was relatively unimportant.

McBride et al. (1993) included the effects of shade in a heat budget model for the Mangatangi Stream, south-east of Auckland. They predicted that decreasing the minimum flow of the unshaded river from 1.0 to 0.2 m^{3}s^{-1} would increase the 5 percent exceedance temperature from 25.9 to 27.7°C, but that replanting the banks with trees had the potential to reduce daily maximum temperatures. McBride's model has recently been modified and used to investigate the role of riparian shade (Collier et al., 1995) but the model can also be used to predict the effects of increasing or decreasing flow.

Given data on temperature changes along the channel at one flow, the method of Dymond (1983) can be used to predict the temperature change at lower flow. Given only meteorological and channel shade data, water temperature can be predicted using heat budget models (Hockey et al., 1982), but these require expert advice. Nomographs are available for predicting the effects of riparian shade (Collier et al., 1995), but none relevant to New Zealand conditions are known for predicting the effects of abstraction.

7.4.2 Dissolved oxygen

Relatively simple methods are available for calculation of DO sags, including the effects of multiple point sources and runoff (McBride and Rutherford, 1983). Methods are available to calculate the likely impact of flow reductions on diurnal variations in DO. It may be that the situation being studied is sufficiently complex (multiple inputs, sag, plus diurnal variation) that more detailed models such as DOFLO should be used (McBride, 1995). Expert assistance is needed for these assessments.

7.4.3 Ammonium and pH

Standard chemistry calculation methods are available for calculation of pH and ammoniacal-nitrogen proportions in waters of stable pH. Expert assistance may need to be sought for the case where pH varies substantially (say above 8.3 units). Variation may be particularly wide where waters are not well buffered.

7.4.4 Nutrients

The general behaviour and problems of nutrients are dealt with in Ministry for the Environment Water Quality guidelines (Ministry for the Environment, 1992). The particular concern is with the stimulation of undesirable biological growths by nutrients. This also requires the input of light and availability of suitable substrate material.

The effect of flow reductions is to reduce the dilution of nutrient-rich waters entering the stream, either from point sources or from diffuse runoff. Simple mass-balance calculation methods may be used to estimate the consequent increase in nutrient concentration. In more complex situations, the effect of internal nutrient removal processes (e.g. plant uptake, bacterial respiration) may need to be addressed by detailed modelling.

7.4.5 Toxicants

Standards methods exist for assessing dilution of discharges containing toxic contaminants.

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8. Technical Assessment Methods for Recreational Values

Resource managers are likely to come across several recreation management tools. Many exist and they are constantly evolving. Amongst the most enduring has been the Recreation Opportunity Spectrum (ROS), and the concepts of social and environmental carrying capacities. The latter concepts are widely accepted, although the means of defining them vary.

For a good overview of recreation management methods, readers are referred to Devlin et al., 1995.

8.1 Recreation Opportunity Spectrum (ROS)

ROS is a common recreation planning tool, developed in the USA in the late 1970s, and most Department of Conservation (DoC) conservancies have undertaken ROS studies within their regions. Such management tools are designed for allocating and managing resources to optimise recreation opportunities.

ROS is not a means of assessing the quality (or significance) of a resource or recreation experience. It is a methodology designed to help identify the recreation opportunities which exist within a management area, and then to allows managers to design and locate facilities, information, and access systems to foster the preferred opportunities. It is essentially a means of matching diverse user expectations with recreation opportunities. The concept of a spectrum is based on the idea that a quality recreation experience can take place in a variety of settings (ranging from urban to wilderness), and that recreationists should be able to move through the spectrum of opportunities as their desires dictate.

Corbett[1] (1995) summarises the ROS methodology as follows (information in italics is additional to Corbett's study.:

1. Estimate demand for recreation opportunities (*that is, what recreation opportunities are being sought by the target population. This population may be local, regional, national or international, commercial or private. Demand is not necessarily related to use that is, demand may not necessarily be expressed*).
2. Assess the range of available opportunities and resource capability by identifying ROS classes (that is, determine the setting, activity and experience characteristics for each opportunity class ranging from urban to wilderness environments). *It is the setting characteristics which will be most significant within the flow-regime assessment.*

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[1] *Managing outdoor recreation. Pp 191 - 214 in Outdoor Recreation In New Zealand. 1995. Devlin P.J. et al (eds). DOC and Lincoln University, Wellington.*

3. Identify current patterns of recreation throughout the region. (*This may be by survey, or some more basic level of assessment (expert interview, for example.*)
4. Use demand and capability data to determine which opportunities to maintain or alter. (*These are management decisions based on the need to optimise resource allocation decisions, based on user demand.*)
5. Integrate recommendations for recreation with other land use objectives in the region (eg, forestry, agriculture, conservation, tourism, development).
6. Develop alternative plans for resource allocation so that recreation and other land use objectives do not clash. (*Note that this is responding to existing conditions.*)
7. Develop management strategies which show how recreation objectives will be achieved.

Considering the wide scope of the information required to develop a ROS planning model, and the focus on developing a spectrum, it is not appropriate to carry out a ROS study for one particular resource. One braided river, for example, is unlikely to provide sufficient environmental variability to offer a true recreation opportunity spectrum. The process is about allocating and managing elements of resources on a regional, or wider, basis. A resource manager seeking data about potential impacts of a change in flow regimes in one or a few locations should be accessing existing ROS studies to uncover relevant environmental, use and demand indicators, which are elements of all stages of the ROS process. If suitable studies do not exist, the manager should seek means of carrying one out for general planning requirements.

A major benefit of the process is its reliance upon the context of the resource. This includes location, access, use and demand-all elements which help define the values associated with a recreation resource.

8.2 Limits of Acceptable Change (LAC)

LAC is generally concerned with the setting of social and environmental standards, and considering what level of change (social and environmental) managers and resource users are willing to accept. This management model came from the same school as ROS, is closely associated with the concept of carrying capacity, and is an extension of the ROS process (Corbett, 1995).

By virtue of its ability to focus on more site-specific issues than ROS, a LAC study can be carried out for a specific location. It would also be a mammoth exercise to carry it out for a region, and possibly even more onerous to implement and monitor. It is significant that no regional LAC study has been undertaken in New Zealand to date, although the principles of the methodology are widely appreciated.

The prescribed process relies upon a ROS study having been carried out previously to define recreation opportunity classes (that is, whether a resource offers an urban or wilderness experience, or something between those classes on the recreation opportunity spectrum). These class definitions will relate closely to the level of change considered acceptable within the relevant location (for example, change is less likely to be acceptable within a wilderness zone than within an urban or peri-urban area).

Corbett (1995) summarises the LAC process as follows (comments in italics are additional). Steps 1 through to 4 are ROS activities.

1. Identify areas, issues and concerns. (*This will include the area to be considered, as well as management concerns, user concerns and other significant issues (Maori, ecological, etc.) which may not be immediately apparent and will require research.*)
2. Define and describe recreation opportunity classes.
3. Select indicators of resource and social conditions. *These will relate to the ROS classes, but should be specific and measurable. A variety of existing studies indicate a variety of indicators which may be used (see Section 5.0 of Corbett.)*
4. List existing resource and social conditions.
5. Specify standards for resource and social conditions in each opportunity class.
6. Identify alternative opportunity class allocations reflecting area-wide issues and concerns and existing resource and social conditions. (*That is, reconsider the allocation of classes in step 2 to the site, and identify a number of alternative classes the resource might fill, based on the status of the resource and the demand factors.*)
7. Identify management actions for each alternative. (*How you would go about achieving those different recreation opportunity classes. In the case of flow regime management, a set of different flow regimes may be mooted, their likely outcomes described within the ROS framework-or another appropriate system.*)
8. Evaluate and select preferred alternatives.
9. Implement actions and monitor conditions.

8.3 Social carrying capacity

The ROS and LAC assessment programmes have as underlying principles the concept of a social carrying capacity. This relates to the effects people have on each other, rather than the effects people have on the environment or vice versa.

The concept assumes that recreationists generally have an expectation about how many interactions with other people they consider to be appropriate for the experience they are seeking. It is a logical assumption, but it may take a lot of research to quantify. For example, Walrond's (1995) study of the social carrying capacity of the Greenstone River[2] for fishing identified that anglers expect three or fewer encounters with other anglers per day, within what is considered a wilderness setting. More than three encounters was perceived to compromise the quality of the experience. (Such information is directly relevant to a ROS strategy.) The study used two full-time hut wardens in the Greenstone Valley and attempted to survey all anglers using the fishery over a six-month period.

The concept of a social carrying capacity may be an issue where a change in flow regime reduces or increases the level of use of a site has. In the case of a reduction in use, the site may fall below its preferred capacity. Swimming, for example, may best take place, with a reasonable number of people, for safety or simply for company. A reduction in use may also cause an increase in use in another location, exceeding that site's capacity. The negative effects of a change in the flow regime may not, therefore, be confined to the river or site in question.

It is clear that a social carrying capacity will vary depending upon the experience sought, and the environment within which the experience takes place. Site specific studies are always necessary.

8.4 Summary of methods

There are very few examples in New Zealand where outdoor recreation planning is carried out with of full information and full adherence to prescribed planning methodologies, such as ROS and LAC. (No full LAC study has been completed in New Zealand.) Rather, a range of site-specific assessments and broad planning decisions are made using the general principles of these methodologies. For example, it is widely held that a range of recreation opportunities should be provided, and that it may be necessary to limit social and environmental impacts to maintain a desired type of experience. As a result of these understandings, many sophisticated management systems have been developed to maintain certain experiences. - consider the Milford Track and the concept of wilderness areas. This planning often uses surveys of users. The implementation of these methods is largely confined to the DoC estate, and they are not widely adopted by local or regional authorities.

It is clear, though, that a systematic approach is available for defining the optimum flow regime relevant to different activities in different locations. The key point to remember is the need to analyse the wider context of the recreation opportunity being considered, and the methodologies discussed encourages this approach.

Several other methodologies are available for recreation planning in natural or semi-natural environments. A number of institutions, consultancies and individuals are available in New Zealand with the experience to modify research methodologies and survey systems to specific management issues.

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[2] *Walrond, C. 1995. Wilderness Fisheries Management - a case study of the social carrying capacity for the Greenstone River. Planning project, M RRP, University of Otago.*

9. How Changes To Flow Regimes Affect Recreational Values

The following sections summarises impacts of change of flow regimes on specific activities

9.1 Consumptive activities - angling, whitebaiting

Angling within New Zealand is relatively well researched, on both river-specific and more general perception and motivation bases. This wealth on information can be ascribed to the activities of the Fish and Game Councils and the Ministry of Agriculture and Fisheries, as well as various studies carried out for hydro developments, and theses and papers completed by tertiary students. It many cases it may be a relatively straight forward matter of carrying out a literature search to obtain site-specific data on flow-regime requirements for angling. This luxury is not so readily available for other water-based activities.

Angling (and quite likely other activities such as whitebaiting) is only partly about catching fish. Walrond (1995) reports on a 1974 study carried out in Utah, USA, suggesting that the catching of fish is a less important motivational factor for anglers than “escaping from routine”, “getting outdoors” and experiencing the wider environmental values of the river environment. Almost a third of respondents to that particular study stated they would not be disappointed if their catch rate was halved (although it should be noted that the survey area featured some highly productive fisheries, and halving a low catch rate would probably be considered more serious).

Teirney and Richardson’s[3] (1992) analysis of the results of the National Angler Survey - begun in 1980 by the then New Zealand Acclimatisation Society - found that the catching of fish appears to be more important to New Zealanders than is reported in other countries. Nevertheless it is generally accepted that it is not just the presence of trout or salmon that contributes to a good fishing experience. In Teirney and Richardson’s words, describing their study:

> *The total number of fishing visits made to each river provided a measure of its relative importance. (However) the relative importance (and presumably therefore the absolute value) cannot be evaluated solely by the reference to measures of angler use. A list of seven other factors believed to be important determinants of high-quality river fishing experiences in New Zealand was compiled .... For each river, anglers were asked to assign a rating between 1 (lowest) and 5 (highest) for distance from home, ease of access, area of fishable water (defined as the area of river bed or bank from which to fish), scenic beauty, peace and solitude, catch rate, and size of fish. The overall importance of each river fished was also evaluated with the same rating scale....*

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[3] *Teirney, L.D. Richardson, J. 1992. Attributes that characterise angling rivers of importance in New Zealand, based on angler use and perceptions. In North American Journal of Fisheries Management 12: pp 693-702.*

> *For trout rivers, our results suggest angler use alone should not be used as an absolute measure of a river's value; none of our three measures of angler use were correlated with anglers' perceptions of overall importance. The rivers used most in New Zealand tended to be close to home and have easy access, whereas the most highly valued rivers were characterised by good catch rates of large fish, extensive areas of fishable water, and scenically attractive and peaceful surroundings....*
>
> *It seems that the hope, even if unrealistic for many anglers, of landing a fish or having an occasional success weighs particularly heavily in the perception of a New Zealand river's value.*

This finding is in accord with Booth and Keys'(1994) results for the Tongariro River study, which found anglers listed, in order, for the "reason for their visit":

- Fishing quality
- Scenic beauty
- Long term association with the river and/or area
- Heard of the river by its reputation.

The ecological integrity of a river, as it affects fish quality (size and condition) and quantity, is therefore vital to preserve the quality of the angling experience, and subsequently the value placed upon the river. The fish, in themselves, contribute a significant component of the total angling experience. The degree of this contribution will vary depending upon the context of the river - its location, reputation, scenic quality, etc (refer to landscape section).

Lists of potential impacts (as follows) will never be sufficient for assessing the true impacts. They will encourage a wider appreciation of impacts, but each site will have some unique use factors which will be difficult, if not impossible, to predict. In all cases, site-specific assessments are necessary.

General factors to consider are included on Table 8.

Table 8 Effects of change in flow regime on fishing activities

Change in physical conditions	Effect
Particulate matter mobile in river, including weed mats, small pieces of floating debris, etc	Fouls lures, clogs nets for whitebaiters
Fixed debris, such as logs, branches, etc	Snares lines
Turbidity	Various effects depending on fishing method adopted (for example, fly fishing is best in clear water, particularly when stalking fish, spinning may be better in slightly turbid water-likewise salmon fishing ("light colour" preferred). Turbidity reduces the ability of whitebaiters to see the bait, which is important.
Controlled flows	A variety of impacts may result through the change in low flows, high flows, the creation of stable flows or the change in seasonal patterns-this requires site-specific assessment. Perceptions may play a large role-anglers may correlate a particular flow level with good fishing, when there may be no causal relationship. This will play a large role with the concept of a controlled or "unnatural" flow pattern generally. A change in flow may also encourage other users (kayakers for example) which may conflict with anglers. Flood flows during whitebaiting are likely to be detrimental (regardless of ecological requirements).
Low flows	May strand launching ramps for boats and change traditional fishing spots. May cause fish to pond, thereby increasing the chance of poaching activities (foul hooking or "scratching"). Fishable area (a key indicator of value) may be reduced (for example, reduced width brings margins of river closer). River character may change (loss of pools, increase in riffles, etc). Exposure of slippery rocks, mud, etc. Impacts on alternative locations may result through dispersal of use to other sites. High or low temperatures affect trout behaviour. Above or below these temperatures trout are relatively inactive and have little interest in feeding. Fish may be more difficult to approach (and therefore catch) even though their ecological requirements are catered for.
Altered form, channel type	Loss of cover for stalking. Changes in access (may be significant for established whitebaiting sites).

9.2 Paddling and floating activities

Sourcing information regarding the possible effects of an altered flow regime on paddling activities is generally straight forward. Canoe and kayak clubs[4] are generally located in all regions and are represented by a national body (New Zealand Canoeing Association). Information on rafting activities is usually accessible from commercial rafting guides or from local or national associations of commercial guides.

Caution is needed in all such research. It is difficult and dangerous to generalise about the flow requirements for activities which feature a wide variety of resource demands and personal preferences. Canoeing and kayaking can and do take place on a very wide range of water conditions. This is exemplified by the method of "grading" used by paddlers (meaning rafters, kayakers, canoeists generally) to signify river conditions and, in an indirect manner, the levels of skill required to enjoy and survive them. The grading system runs from one to six, and is described in many texts, with several small differences in wording[5] (Egarr and Egarr, 1981). Interpretation of the grades is partly subjective, and river users may debate their individual assessments of grade for a particular stretch of water. The grades will obviously change for any one stretch as flow conditions alter.

If a river which is used by paddlers is subject to a change in the flow regime, it is highly likely that some impacts will result. The scale of the impact will vary depending upon the intensity and type of use and the form and context of the river. This must be assessed on a site-specific basis, although any river which receives at least a moderate level of use is very likely to appear in a number of texts and guide books. (Contact a local canoe club or the New Zealand Canoe Association for the latest publications.)

Omission from such publications is still no guarantee of low or no use. A significant paddling activity is the exploration of small or well-hidden waterways, and although infrequently visited, waterways which may offer a 'sense of discovery' to paddlers are important. A good example is the myriad of creeks running into Tauranga Harbour, which offer a reasonably significant paddling opportunity (albeit in many cases, very short).

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[4] *There is often confused between these two craft. In a canoe a paddler kneels and uses a single bladed paddle. The boat may have an enclosed deck, or be open as in a Canadian canoe. A canoe is of American Indian origin, originally constructed partly from bark. In a kayak a paddler sits and uses a double bladed paddle, and the boat generally has an enclosed deck. A kayak is of Inuit (Eskimo) origin (hence the 'Eskimo roll'), originally constructed with animal skins. Despite this difference, the term 'canoe' is often used to include kayaks (but not generally vice versa). A 'canoe club', for example, often has more kayakers than canoeists as members. 'Canoe polo' is usually played in short kayaks.*

[5] *See Egarr, G.D. Egarr, J.H. 1981. New Zealand recreational river survey. Three volumes. Published for the NZ Canoeing Association by the National Water and Soil Conservation Organisation, Wellington.*

There are several good examples of controlled rivers being managed for recreational and commercial paddling, in a reasonably successful manner. The Wairoa, in the Bay of Plenty, is one good example. Flows are released at times agreed between the Kaimai Canoe Club, based in Tauranga, and the controlling authority. This allows very predictable flows at predictable times, but has created some significant problems with overcrowding, as commercial and private rafting operators use the river alongside kayakers. Conflicts occur when a kayaker wishes to play in a wave or hole, and a raft passes through with little stopping ability.

Table 9 Effect of change of flow regime on paddling and floating activities

Change in physical conditions	Effect
Particulate matter mobile in river, including weed mats, small pieces of floating debris, etc	Few concerns beyond aesthetic if debris is small.
Fixed debris, such as logs, branches, etc	Can pose very serious risks for paddlers (pinning). If stationary large debris are termed strainers. If mobile, termed mobile strainers. Strainers may take many forms, including willow roots and branches (live) and dead trees.
Turbidity	Is unlikely to alter the physical ability of the river to support the activity but may reduce the quality of the experience, particularly where the natural character of the river is significant (consider the Whanganui).
Controlled flows	A variety of impacts may result through the change in low flows, high flows, the creation of stable flows or the change in seasonal patterns. This requires site-specific assessment, as river hydraulics will change with flow regime, and many river features (holes, waves, rapids, etc) are dependent on specific flow levels. Perceptions of control may play a large role, as for anglers. Concentration of good flow patterns at particular times may cause or increase crowding. Reliability of flow can be an improvement, although variability may be sought by many users. Different flows may expose or hide many hazards (undercut rocks, strainers, for example).
Low flows	May strand launching sites, expose mud and slimey rocks and will change river hydraulics (as above). In some cases the river may be more user friendly at low flows, but such a state is likely to satisfy only a portion of the user population. Dangerous strainers are often exposed, and low flows will not necessarily reduce the risks of being pinned.
Altered form, channel type	Changes in access. Changes in hydraulics, possible loss of many features of river (as above).

9.3 Swimming

Identifying swimming locations on rivers can be problematic. There are no representative associations, and the naturally dynamic nature of a river may result in swimming pools being created or filled over short periods. Swimming may also take place in a river of virtually any size, depending upon access and some safety considerations (depth[6], hidden obstacles - “strainers” are also a significant threat to swimmers).

Swimming is often located near obvious nodes, including marae, bridges, roads, road ends, picnic areas, tracks, huts, waterfalls, river beaches, slow flow areas and pools at river bends, population centres, and outdoor education centres.

It is necessary to carry out observation analysis studies and interviews with knowledgable locals to identify swimming locations and minimum requirements.

Table 10 Effect of change of flow regime on swimming activities

Change in physical conditions	Effect
Particulate matter mobile in river, including weed mats, small pieces of floating debris, etc	May reduce the use of a site significantly. Mobile phytoplankton (algae) would be of concern. Perceptions of water quality are important (it is difficult to subjectively judge water quality, and what is visible will guide that judgement).
Fixed debris, such as logs, branches, etc	Can pose very serious risks for swimmers (entrapment).
Turbidity	Perceptions of water quality are significant, and turbidity will have a significant effect, as for particulate matter. Dangers (strainers, rocks) may be obscured. The natural character of the river is likely to be important (odours, reflections, clarity, etc).
Controlled flows	A variety of impacts may result through the change in low flows, high flows, the creation of stable flows or the change in seasonal patterns this requires site-specific assessment, as river hydraulics will change with flow regime, and many river features (holes, waves, rapids, strainers, etc.) are dependent on specific flow levels. The natural character of the river is likely to be an important element of the experience (sound of riffles, etc.)
Low flows	Exposed mud, slimey rocks and siltation are major issues. Shallow pools and reduction in depth may reduce swimming opportunities, and may remove jumping sites (need depth). In some cases the river may be more user friendly at low flows, and temperature in pools may increase.
Altered form, channel type	Changes in access. Changes in hydraulics, possible loss of many features of river, such as swimming holes.

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[6] *Consider a swinging rope left over what was once a deep pool. The invitation will exist for swimmers to use the site and assume that the depth remains.*

9.4 Mechanical activities

Jet boating activities are governed by national and regional rules. The Harbours Act 1950 allows the setting of regulations to control the activities of all water-borne craft (section 241A). The Water Recreation Regulations 1979, operating under the Harbours Act, sets a variety of conditions upon the use of motor craft (and most other vessels). Small craft (vessels under 30 metres in length) are set specific speed limits (s.7(1)); specifically a proper speed (relative to the water) not exceeding 5 knots within 30 metres of any vessel and within 200 metres of the shore or of any structure.

This regulation would severely limit the abilities of almost all motorised craft to access rivers (they generally being narrower than 400 metres, and power boats being unable to plane at less than 5 knots) if it were not permitted by section 232 of the Harbours Act and sections 20 and 21 of the Water Recreation Regulations for various agencies (local authorities, harbour boards, etc - the 'supervising officer') to uplift the restrictions in certain cases. The New Zealand Jet Boat Association Yearbook (PO Box 339, Christchurch) aims to describe the status of all New Zealand's waterways in terms of uplifted regulations. Further uplifting of the regulations or interpretation of the regulations may be undertaken by relevant regional or district authorities. (It is necessary to check in each case[7]. Some restrictions appear in some district plans.)

It should be noted that the Harbours Act is currently under review, and there are generally few consistent treatments of the regulations from authority to authority. It is necessary to check with the Ministry of Transport, Local or Regional Authority, Maritime Safety Authority or local branch of the Jet Boat Association for relevant information.

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[7] *For example, the Lakes District Waterways Authority (Shotover River) Empowering Act 1985 and the Queenstown Lakes District Plan limit the jet boating use of the Shotover Canyon to one commercial jet boat operation (Shotover Jets) for safety reasons.*

Table 11 **Effect of change of flow regime on mechanical activities**

Change in physical conditions	Effect
Particulate matter mobile in river, including weed mats, small pieces of floating debris, etc	Floating matter of any sort may damage intake ports, water pumps and the general drive mechanism of jet boats. Large debris (branches) may puncture a boats hull at high speed.
Fixed debris, such as logs, branches, etc	Can pose serious risks to vessels.
Turbidity	Fine matter may seriously damage water pumps and the propulsion mechanism of jet boats and jet skis.
Controlled flows	A variety of impacts may result through the change in low flows, high flows, the creation of stable flows or the change in seasonal patterns. This requires site-specific assessment, as river hydraulics will change with flow regime, and many river features (holes, waves, rapids, etc) are dependent on specific flow levels.
Low flows	May strand launching facilities. In braided rivers, can reduce quality of experience by reducing area of resource. Jet boats plane over very little water, but require deep pools for take-off and for stopping. Exposed mud, slimey rocks and siltation are issues, although some reports suggest weed on rocks may protect hulls. Mud may trap launching vehicles. In some cases the river may be more 'user friendly' at low flows. Safety may be compromised during low flows. Jet boats generally keep right as a rule, but in narrow gorges where visibility is restricted, collisions may be a potential - and more-so when river width is reduced. Reduction in width will increase conflicts with shore users (anglers, whitebaiters) and other river users (kayakers, etc).
Altered form, channel type	Changes in access. Changes in hydraulics, possible loss of many features of river, such as take-off and stopping areas, as above.

9.5 Other activities

Other river-based activities include:

- Tubing (floating with or without paddles in inner tubes - Prefers more gentle and deeper water than kayaking or rafting)
- Black-water rafting (similar to tubing but through caves - generally commercial)
- Pack floating (using a tramping pack for buoyancy - same conditions as tubing)
- River boarding (riding rivers using a closed cell foam board; can operate in - and prefers - high volume and grade water (up to 5) - generally commercial)

- River sledging (similar to river boarding although a plastic pod is used instead of a board - generally commercial and not as extreme as river boarding)
- River surfing (requires large standing waves and uses surf boards - often requires flood conditions and high skill levels)
- Gold panning (can operate in a range of conditions and may be offered commercially)
- Dinghy riding (drifting - can be carried out in a range of conditions, similar to kayaking)
- Drift diving (not often a recreational activity, often associated with research and so may take place in a wide range of rivers)
- Ecological studies (educational or special interest groups, a wide range of rivers)
- Adventure education (may include a number of pursuits, including flying foxes, swings, abseiling into or near rivers, wire walks across rivers, etc, and many take place in, over or near any type of river).

9.6 Studies into the impact of controlled rivers on recreational values

Few comprehensive studies have been carried out on controlled rivers to assess the impacts of the flow regime on recreationists, although many studies have been carried out for angling. One of the most significant is the Tongariro River Recreation Study undertaken (Booth and Keys, 1994). A key element of the research undertaken was the formal interviewing of key informants people who used the river a great deal or who knew much about particular activities. Although the following list is not activity - specific, the comments give a clear picture of the types of indicators we are seeking, as they relate specifically to the impacts of a controlled flow regime.

The interviews were structured to give an understanding of the advantages and disadvantages of a controlled flow regime, and how these were represented in summer and winter. The following comments are summarised in the original report. Note these are comments made by a few well-versed individuals and so are not able to be statistically analysed or compared for relative weight, although 17 separate mentions were made of advantages of the flow regime compared with 34 mentions of disadvantages. Also, the statements are not coded to different user groups (such as anglers and rafters) although it is generally clear which user groups most statements represent. Comments recorded are:

"Advantages" of current flow regime

Summer users

- Consistent flows which are predictable and more manageable.
- Floods are controlled which increases the days on the river.
- Higher water levels in summer (than under natural flow regime).
- Good holes for water craft to play in.
- Hydraulics of the river are challenging at lower flow levels.
- Increased slime on rocks reduces damage to watercraft.
- Can get advice of flows in advance which helps trip planning.

Winter users

- Increased fish spawning through increased siltation (compared with natural flow scenario).
- Water clears more quickly after a storm (than natural flow).
- Easier to wade in the river as it has silted up - fish are more accessible.

"Disadvantages" of current flow regime

Summer users

- Simply that the river was too low.
- Slow trips down the river and less exciting (less whitewater)-more portages necessary-clients can get cold and exhausted/hypothermic.
- Increased wear and tear on craft-a lot of damage to paddles etc.
- Rocks are slippery and potentially dangerous to rafters/kayakers.

Winter users

- Increased siltation of the river and pools.
- Nymphs are smothered by truncated recessions.
- Increased siltation reduces places for trout rearing reduced size of pools which hold fewer fish.
- Fluctuations in water level is detrimental to the insect life and young trout.
- Slime gets caught around fishing lines.
- Slimy rocks are less aesthetically pleasing.
- Don't like walking in the silt/sludge.
- Fewer good fishing spots, and this results in more anglers in the suitable pools.

9.7 References

Booth, K. and Keys, H. 1994. Tongariro River Recreation Study (2 vols). Prepared for the Department of Conservation, Turangi. Tourism Resource Consultants and Department of Conservation

10. How Changes to Flow Regimes Affect Landscape Values

10.1 The wider landscape context

It is not easy to separate a river's qualities from those of its wider landscape context. The discussions in Volume A have, on a number of occasions, made reference to landscape setting. In any discussion on the landscape implications of manipulating flow regimes the question of context is bound to arise. Some will argue that a river landscape cannot be separated from its broader catchment. In the case of Water Conservation Orders, it is the waters themselves or the contribution they make to wild and scenic values that need to be considered. Consequently, the surrounding landscape is significant in determining the value of a river only if that landscape contributes to the water's landscape qualities. For example, a river in undulating hill country surrounded by dense bush will draw largely on the quality of the nearby bankside vegetation. In the case of a glacial valley such as the upper reaches of the Shotover, the river is a dominant feature in the wider landscape and draws its quality from its spacious surroundings including terraces, mountain slopes and distant ridges.

The issue of context is important on two counts. The first is the relationship of the river to its surroundings, as these will influence the river's perceived quality and therefore the need to address landscape issues as part of instream management objectives. The second is the significance that should be attributed to landscape concerns when determining flow regimes - particularly low flows. If a river is seen as integral with its broad landscape setting, then clearly a changed flow regime may have effects well beyond the riverbank. Consequently it is important to attempt to define the spatial influence of a river before addressing the extent of impacts. The only common sense approach is to address each river on a case-by-case basis. However, there are likely to be similarities between similar river (flow regime) types.

10.2 Flow regime types

The relationship between rivers and their landscape contexts reflects the scale and nature of the landscape. In some instances rivers may only be experienced from nearby because of the enclosing landform. In other instances a river may be a prominent component in a large-scale landscape. These differences broadly relate to the flow regime types as described previously in Volume A. The general relationship that rivers have to their landscape context are as follows :

- Lake or spring fed - these rivers are often set in small scale landscapes where the river is only locally significant and the relationship between river and landscape may be restricted to the adjacent riparian area.
- Low relief country - moderate and local relationship, largely restricted to adjacent riparian areas and surrounding slopes.
- Inland hill country - moderately strong but highly variable relationship, reflecting gorge and valley topography.
- Non-glacial and glacial mountains - strong relationship in tussock country due to expansive valleys resulting from fluvial processes; less strong where bush present. River may 'nest' within wider valley landscapes that themselves nest within inter-montane basins.

In all flow regime types these relationships are generalisations and variations will occur.

10.3 The effect of change of flow regime on landscape values

Changes in flow regime affect the landscape in a variety of ways and through a number of mechanisms. Consideration must be given to flow variability, changes to water quality and the particular low flow geometry of the river.

10.3.1 Flow variability

Unmodified flow regimes display a wide range of variability. To a greater or lesser extent, this reflects the flow regime type (see Table 1). Some rivers display a relatively constant flow regime e.g. lake-or spring-fed rivers, others display a highly variable regime e.g. South Island rivers with their source in the Alps. In many rivers there are major variations in flow from year to year. This is the complex baseline against which changes in the flow regime must be measured.

Clearly the effect of a change in flow will vary depending upon the perceived natural variability. The same flow change is likely to have a greater effect in stable lake - or spring-fed rivers. This relates to the viewer's expectation and to the river's ecological ability to adjust to flow variability. An example of a special case would be a river affected by tidal influence where water levels fluctuate with the tides, such as Heathcote River in Christchurch.

The way in which flow changes affect the natural river flow will result in different effects. A minor and short lived adjustment to flood flow durations is likely to have a very different impact from a major increase in frequency and magnitude of low flows (refer to Volume A, Table 4).

The landscape significance of a changed flow regime is dependent upon the particular landscape values likely to be affected. In a wild and isolated river the issues are likely to be those of intrinsic values and natural character. These issues may apply at all times, whereas popular values may be time dependent. For example, flows may only be an issue during the warmer swimming months, or during the fishing season.

A reduction in flows has an impact on the 'feel' of a river. For example a loss of drama in areas of rapids or a reduction in the speed of flow through a gorge. It may change a river from a smooth flowing surface to one with riffles or a broken surface. The extent of water surface visible in a riverbed is a major influence on how the river is perceived. Flow modifications that alter the natural balance between open water and rock, gravel or bank exposure can have adverse effects on people's perception and experience of a river landscape. Whether these changes are of landscape significance will be dependent upon the values attributed to the river prior to modification.

10.3.2 Water quality

There is a distinction between subjective measures of water quality as it influences landscape values and scientific measures of water quality turbidity, clarity, pollution, etc. Generally, key concerns will be the presence of human and natural rubbish, and turbidity or discolouration.

Natural 'rubbish' is likely to be composed of plant material that has entered the river, often during storms, and then becomes trapped. In wilderness environments this may be perceived as part of the wild character of the river, but in urban areas it may be considered unsightly or unscenic.

Human rubbish, such as plastic, can have a significant impact on the aesthetic quality of a river, particularly if there is a build up of litter in a high profile location. Changed flows can affect this for example, in the event of reduced flows rubbish may not be flushed. Flow variations can also result in litter being left on banks after high flows.

These issues strongly influence people's perception of water quality, particularly in tranquil locations. They may well be significant in spring - or lake-fed rivers and in gentle flows in 'low relief country' rivers. They are less likely to be an issue in rivers with stronger currents.

Water colour and clarity are discussed in an Ministry for the Environment (1994) publication[8]. Turbidity is a natural characteristic of flood-prone rivers and also where 'estuarine' conditions occur near river mouths. Nonetheless, water clarity and colour are treasured qualities of many New Zealand rivers. A reduction in clarity or a loss of particular colouring can have an adverse impact on 'natural character', aesthetic values, sense of place and amenity values particularly if fish are no longer visible.

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[8] *"Water Quality guidelines No.2: guidelines for the Management of Water Colour and Clarity"*, 1994

A changed flow regime could potentially impact on water clarity and colour, for example, by reduced flow in a clear mainstem resulting in less dilution of a turbid tributary. A substantial loss of water flow in a river highly prized for its clarity and colour, e.g. The Blue Grey River, could result in a significant aesthetic and amenity loss.

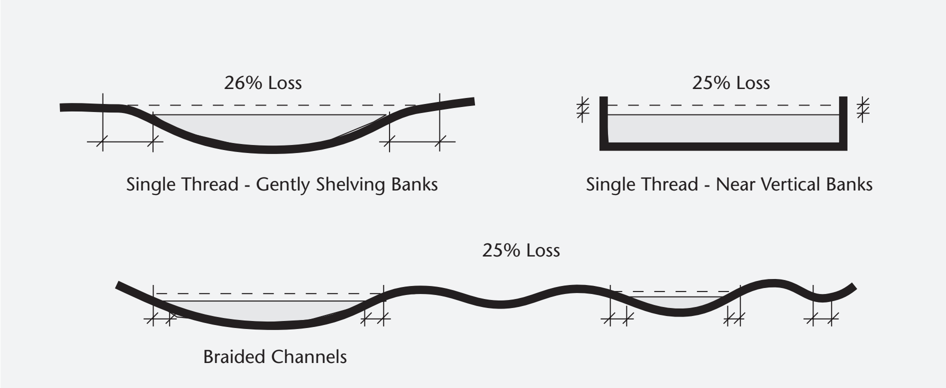
10.3.3 Changes in hydraulic conditions

The likely landscape effects of low flow will depend on channel type. A channel type classification has been made elsewhere in this report based on channel geometry. The three principal forms are (for further explanation see Volume A, Table 3):

- Single thread uniform channels
- Single thread non-uniform channels
- Braided channels.

The effects on landscape values of a given changed flow will vary depending on the channel form. The most apparent effects will be on a single thread river in reaches where there are gently shelving banks that will be exposed during low flows. A similar flow reduction in a river with steep vertical or near vertical banks will be less as the extent of exposed bed will be less. In the case of braided channels the perception of water loss is likely to be less critical because in most natural low flow conditions, exposed gravel banks comprise a significant proportion of the bed.

Fig 37: The same change in flow will have different landscape impacts depending upon channel type.



The natural variability of flows is connected to low flow geometry. For example in rivers where natural low flows are unusual, the effects of prolonged, artificial low flows are likely to be significant. This is a consequence of lengthy exposure of normally submerged mud banks. In rivers where natural flows are highly variable, the effects of modified low flows will be less significant.

It will be apparent that each river will be different depending upon the existing flow regime, low flow geometry, water quality, nature of the flow changes proposed, and the human context within which they occur (wilderness, urban, etc).

Landscape values may also be affected by secondary and tertiary physical and natural consequences of flow modifications. The most significant indirect effects will be modifications to the river bank and bed topography and the creation of conditions that result in changes to vegetation and fauna.

10.4 Changes to riverbanks and beds

Natural bank and bed changes are most likely to occur in large braided mountain-fed rivers where major floods occur regularly. Changes resulting from an artificialyl altered flow regime may not be readily apparent in this environment. In low relief country there is greater stability in natural flows. Therefore, if a major change to flows results in physical changes to beds or banks, these may be readily apparent and may have significant adverse landscape effects.

A more frequent scenario resulting from altered flow regimes is modification to riverbed vegetation. Because of natural river dynamics, riparian vegetation communities often include opportunist species, both exotic and native. Flow regime modifications that involve reductions of flood flows or lowered base and low flows will result in plant community adjustments. For example, in controlled braided rivers, gorse and broom in particular are likely to invade the gravel banks. This in turn provides cover for predators, which may exacerbate the effects of habitat losses for riverbed nesting bird species. This will have an adverse effect on intrinsic, natural and ephemeral landscape values in particular.

Low flows in single channel rivers will in time result in permanent bankside vegetation establishing on the old bed, narrowing the channel and reducing the river’s apparent stature. It may also affect access to the river.

10.5 Summary of effects of change of flow regimes on river landscapes

Flow regime modifications affect landscape values both directly and indirectly. The effects may be restricted to the river itself or extend out into the surrounding landscape, largely depending on flow regime type.

Direct effects result from the mechanisms of flow variability, water quality, and low flow geometry. These are different in all unmodified rivers and change will only be significant where modifications can be differentiated from natural dynamics. The scale and nature of flow regime changes is critical but generally it will be unpolluted single stem rivers with low natural flow variability that will be the most sensitive to change. The highly variable, braided rivers will be the least sensitive.

Indirect effects result from physical changes to bed and banks and also to vegetation and wildlife as a consequence of flow regime modifications. Landform changes that do occur are likely to have the greatest impact in low relief country. Artificially induced changes to bed and banks in braided rivers may not be distinguishable from the results of natural flow change. Vegetation and wildlife changes may be greatest in the braided rivers with their source in the mountains. However, the extent of adverse changes may be difficult to determine due to natural variability of river flows.

11. How Changes to Flow Regimes Affect Maori Values

The following sections discuss impacts of change of flow regimes on:

- Mauri
- Mahinga kai
- Waahi tapu.

11.1 Adverse effects of flow regulation on mauri

Mauri is an extinguishable value. The loss of mauri is recognised by the degraded state of a waterbody and the loss of its life-supporting values. The mauri of the many rivers has been seriously eroded.

Practices that impact on mauri include:

- reductions in flow resulting from diversions and damming
- diverting or mixing water from one waterbody into the catchment of another
- excessive abstractions
- contamination and degradation of water quality as a result of point discharges (including sewage) and non-point discharges.

Regulation of a river flow can change the characteristics of a river[9], which collectively contribute to its mauri, for example:

- The "moods" of a river describe the seasonal changes that, in part, give the river its character i.e. the pattern of low flows, flood flows and freshes. The moods or flow variability may change as a result of regulation.
- A river flows from its source in the mountains to the sea, thus land and sea, the domains of Tane and Tangaroa, are linked. Diversions, damming and abstracting water often sever the flow of water throughout the system and consequently sever the mauri of the river.
- Flows within a waterbody carry sediment, both suspended sediment and bedload. Flow modification can alter the patterns of sediment deposition which in turn can "clog" reaches of the river which previously, as free-flowing reaches, were used and valued by iwi.
- Water, having flowed from its source and reached the end of its journey at the coast needs to be able to leave the river system and mix with the ocean waters. Modification can result in a flow that is insufficient to maintain an open river mouth.

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[9] *See the discussion in "Variables controlling river systems" and "Variables of importance to river biota".*

- Reduced flows within a water body may limit or destroy the ability of the river to cleanse itself. Flood flows in a water body help:
    - remove excess growths such as periphyton
    - dilute the level of contamination in a waterbody
    - remove debris through the system.

The inter-relationship between the land, sea and the coast is affected by flow regulation. In certain parts of the country iwi suspect that flow regulation has impacted on coastal processes by disrupting the natural movement and deposition of gravel on coastal beaches.

With respect to the abstraction of the water, the perception of iwi is that water managers tend to accord priority to abstractive uses and often instream values, including the values of iwi, suffer.

11.2 Adverse effects of flow regulation on mahinga kai

Past water management practices have impacted on mahinga kai. Iwi have repeatedly voiced their concerns at the degradation of lakes, waterways, fisheries and estuaries that formerly supported diverse and plentiful supplies of mahinga kai. The last three decades have seen a marked decline in the quantity and quality of mahinga kai as a result of forest clearing, effluent disposal, eutrophication, damming of rivers, flood protection works including channelisation, wetland destruction and water diversions and abstractions. These interventions have resulted in the following adverse effects on mahinga kai.

- Modifications have resulted in the loss and destruction of habitat and contributed to increased difficulties of upstream and downstream passage for migratory species. For the sustainable management of migratory fish species, upstream and downstream passage needs to be assured.
- The introduction of exotic species has impacted on mahinga kai. For example, the introduction of salmonids, together with flow regulation, has resulted in the loss of habitat for native fish as the regimes in regulated rivers are often more suitable for exotics. A mahinga kai study of the Waitaki Catchment showed that the regulated rivers of the Upper and Lower Ohau River and the Tekapo River provided extremely stable flows, fed to a large extent by groundwater. The rivers were no longer very suitable for some indigenous species and it is widely acknowledged that the Tekapo River is now a major trout fishery. Native fish species may have difficulty competing with the introduced salmonid species especially for space and food. Hydroelectricity generation and abstractions have stabilised flows, allowing salmonids to gain footholds that were once beyond their domain.

- Regulation of river flows can adversely impact on access to mahinga kai. For example, diversion of the Kaituna River, out of the Maketu Estuary, meant that there was an ineffectual flow of water through the estuary. Siltation was another averse effect resulting from the diversion. An indirect effect of the diversion and the sedimentation was the inability to navigate the estuary or launch a boat. This impacted on access to mahinga kai.
- Reduced flows can result in the encroachment of introduced plants into a riverbed or lakebed. This invasion can damage the habitats of indigenous species. Vegetation can also provide habitat for predators that prior to flow regulation could not access species whose preferred habitat is the riverbed. For example, the encroachment of vegetation into the beds of the braided rivers of the Upper Waitaki, which have been largely dewatered as a result of the Upper Waitaki Power Development, provided cover for predators to the detriment of the black stilt. A programme to mitigate this was introduced in 1991.

11.3 Adverse effects of flow regulation on waahi tapu

- There are many issues associated with the appropriate management of waahi tapu, but three directly related to the management of the flows within a water body that need to be reinforced.
- Islands that are located within a riverbed are often waahi tapu. Many represent unique ecosystems. Flow regulation can impact on these sites by:
  - enabling the public to access waahi tapu that were in the past inaccessible
  - enabling predators to access the island
  - minimising the magnitude and incidence of flood flows that may have been necessary to maintain the unique environments on the island
  - in the case of damming proposals, inundating the island.
- Many waahi tapu are located on riverbeds or are adjacent to waterbodies. They can be adversely affected by flow modifications. For example, where control of a water body has increased the flood risk (as a result of sedimentation) waahi tapu may be affected. Waahi tapu can also be effected by the construction activities that are undertaken as part of river stabilisation schemes.
- The increased risk of weed invasion as a result of flow modification has already been discussed. Special controls will need to be instituted to ensure that as a consequence of reduced river flow, the encroachment of weeds does not desecrate waahi tapu.

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Worked Examples and Case Studies

In the following chapters, three worked examples on the application of technical assessment models for ecological values are presented:

- Water quality assessment: “Regional method” using dissolved oxygen modelling
- Habitat assessment: “Regional method” using IFIM
- Using technical assessment methods to assess the use of riparian management as a remedying measure.

A habitat case study is also included in this section to show how effects on ecological values can sometimes be mitigated and remedied.

These worked examples aim to illustrate how:

- Instream management objectives were set. It should be noted that these examples were developed prior to the terminology and approach developed in these guidelines. We have attempted to fit case studies into the approach set out in these guidelines.
- Conflict was resloved between competing instream and out-of-stream values. Although resolving this competition is beyond the scope of these guidelines, some of the case studies provide useful examples of how conflicts were resolved. Some of the case studies are still going through the statutory process and the conflict has not been resolved.
- Technical methods discussed in the guidelines, such as IFIM and water quality modelling are used.

12. Dissolved Oxygen Modelling

Sometimes regional methods can be used to apply technical methods to all rivers in a specified region or sub-region. This case studies describes a regional approach to setting flow regimes for lowland reaches of Northland rivers.

Flow regimes for ecological values should consider water quality, habitat and flow variability (Volume A, Section 10.2). An initial assessment of Northland's rivers identified dissolved oxygen (DO) as a key water quality concern or "critical factor". DO is significant because macrophytes in Northland's rivers can cause diurnal variations in dissolved oxygen, with low DO levels at night. This is a concern because fish and aquatic invertebrates require specific amounts of dissolved oxygen 24 hours a day.

12.1 Instream Management Objective

Using the terminology developed in the guidelines the Instream Management Objective at the policy level was to avoid adverse effects on aquatic life, while at the technical level the following was set as the Instream Management Objective for Northland's rivers:

- To ensure there is sufficient water to maintain DO at > 6 mgl^{-1} (absolute minimum). This value was derived from the ANZECC guidelines for fresh and marine waters, as a limit below which significant adverse effects on aquatic life would occur.

The approach taken to resolving conflict between instream and out-of-stream values was to set an ecological "bottom line", in terms of water quality, that could not be exceeded.

12.2 Technical Assessment Method used to set the Flow Regime Requirement

Modelling was undertaken by Northland Regional Council at eleven lowland sites to predict the effects of abstraction on dissolved oxygen. These sites were selected as Northland Regional Council had previous monitoring data. The rivers have significant macrophyte growths.

A model developed by NIWA, called DOFLO, was used to predict dissolved oxygen content in streams at different flows. The application and effectiveness of the model in a regional approach depends on the rivers being of a similar character. This is a fundamental assumption in all regional approaches.

Firstly, the DOFLO model was calibrated. DO recorders were installed at each site. The diurnal DO record for a particular site was used to infer the magnitudes of the three fundamental parameters that govern dissolved oxygen variation in Northland rivers. These are:

- Re-aeration coefficient - coefficient of proportionality between re-aeration rate and dissolved oxygen deficit.
- Maximum daily plant photosynthesis rate, which occurs at solar noon
- Respiration rates.

In the second part of the modelling exercise, the calibrated model was used to predict the impact of reducing stream flows on dissolved oxygen.

12.3 Results

Except for one stream, the estimated 1-in-5-year low flow appeared to provide sufficient water to maintain the dissolved oxygen standard of 6 mg/l. The DO modelling suggests that a 1-in-5-year low flow should be adequate for maintaining DO in most rivers of Northland. The graphs below show the variation in dissolved oxygen with different flows (Figures 38 and 39).

Fig 38: Dissolved oxygen calibration at a flow of 50.1 litres per second and predictions for 25, 35, 75 and 100 litres per second for the Okarari River (Stanners). (source: McBride and Nagels, 1994)

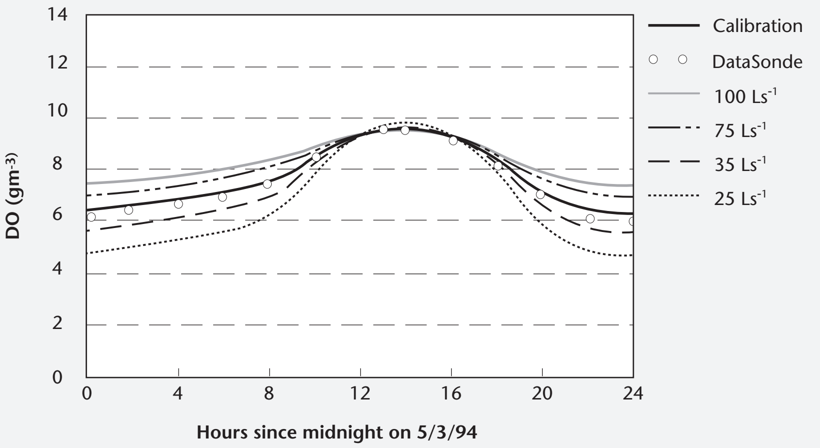
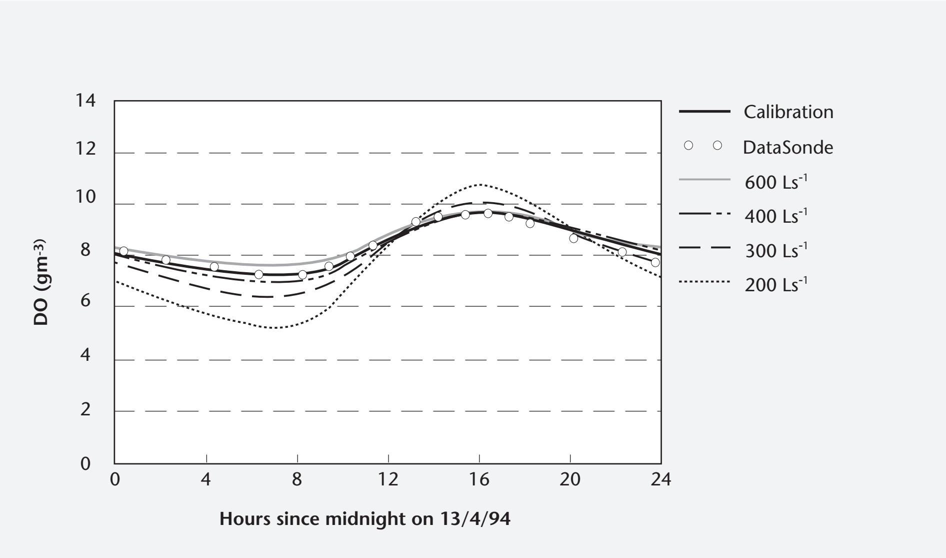


Fig 39: Dissolved oxygen calibration at a flow of 457 litres per second and predictions for 200, 300, 400 and 600 litres per second for the Awanui River (School Cut). (source: McBride & Nagels, 1994)



12.4 Conclusion

In this case study, dissolved oxygen was identified as a critical factor that would cause adverse effects on aquatic ecosystems when flows were reduced. Using the terminology developed in these guidelines, a Flow Regime Requirement that equates to the 1 in 5-year low flow is needed to achieve the Instream Management Objective in lowland Northland rivers.

12.5 Limitations and further work

The DOFLO model is limited by the many assumptions. For example:

- The model uses some untested theory on how re-aeration changes with stream flow. Re-aeration tends to increase as flow decreases, so that severe deoxygenation may not necessarily result. However there are very few investigations which can be used to define the re-aeration coefficient, and therefore any modelling process has to be based on expert judgements, rather than sound relationships.
- The way the results are used in a regional approach assumes the range of sites investigated are representative of the rivers in the Northland region in general.
- The procedure assumed that at the different flows the same amount of plant material was present. But plant abundance and the proportionality of photosynthesis and respiration rates may vary with flow.

Also the DOFLO model does not take some parameters into consideration. For example:

- Shading influences dissolved oxygen content by slowing down photosynthesis. DOFLO does not explicitly consider the effects of shading. But shading is considered implicitly in that a user should calibrate using low values for photosynthesis and respiration rates if there is shading.
- Sediment and organic loading is not considered explicitly by the DOFLO model. However this parameter is considered implicitly in that the suspended sediments may affect the numerical values the DOFLO user provides in calibration for the respiration rate and photosynthesis rate.
- Depth and velocity are considered implicitly in the formulation of the re-aeration coefficients variation with discharge.

12.6 References

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McBride, G.M. 1995. How low can you go: DOFLO - predicting dissolved oxygen levels in streams. *Water and Atmosphere* 3(1) p.17

McBride, G.M; Nagels, J.W. 1994 Analysis of continuous diurnal dissolved oxygen measurements in eleven Northland streams. *Consultancy Report No. NRC004/1*, NIWA Ecosystems. Hamilton.

13. Regional IFIM Approach

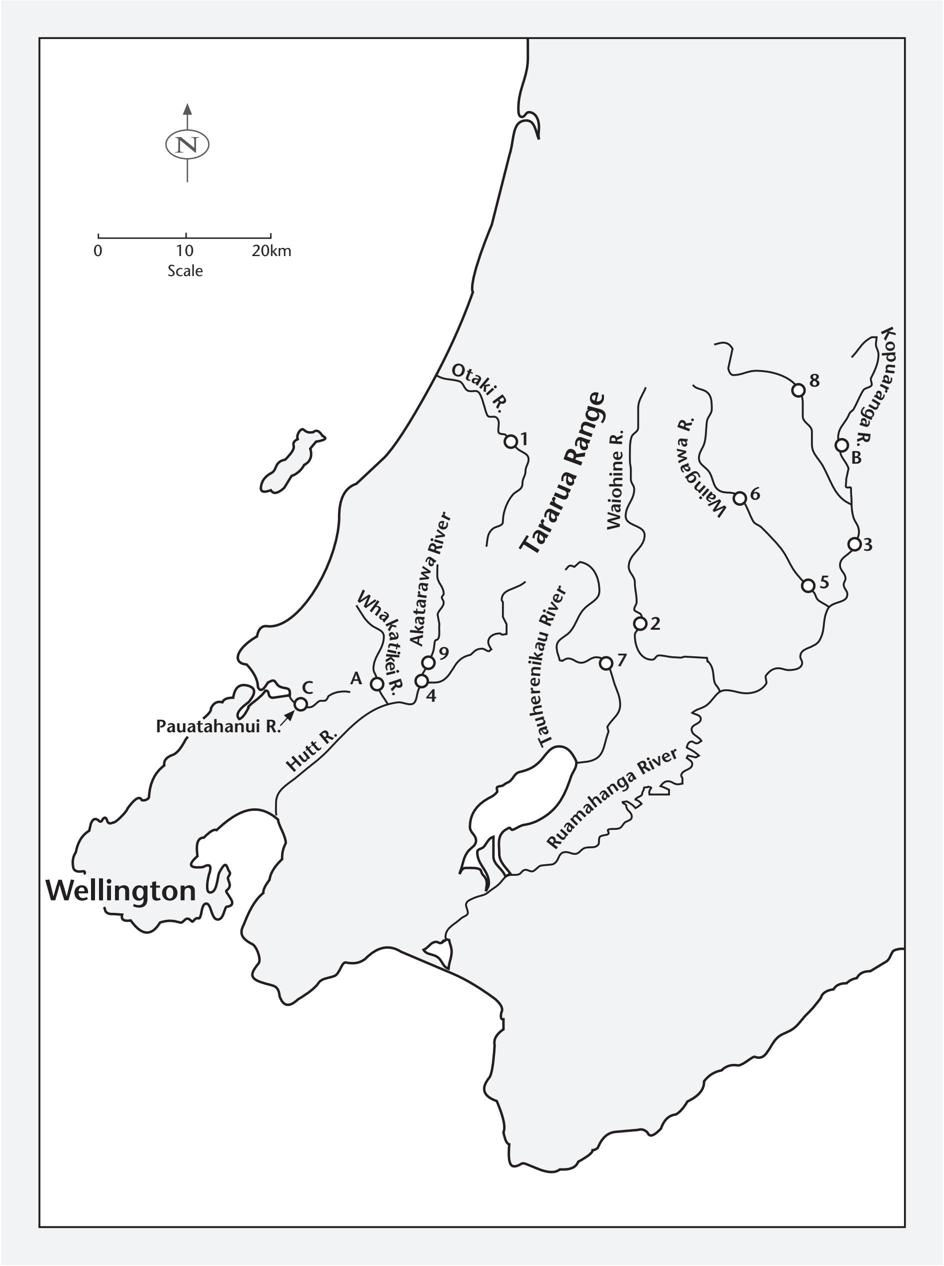
As discussed in Volume A, Section 10.2, account needs to be taken of water quality, habitat and flow variability when setting flow regimes. This worked example is on using IFIM to assess minimum flows for instream habitat, in particular the habitat of brown trout. It is based on an investigation carried out by NIWA in 1993 for the Wellington Regional Council (WRC). For a full explanation of this example, see Jowett (1993). The WRC carried out a further detailed study using IFIM on the Waikanae River. Hayes (1993) has reported on this additional work.

The WRC sought the information to assist in planning for river flows and water allocation. The purpose of the study by Jowett was to use existing "100 river" instream habitat survey data from Wellington rivers plus data gathered jointly by WRC and NIWA staff from two additional rivers to:

- Determine the "habitat quality" of those rivers relative to others in New Zealand
- Determine instream flow requirements for those rivers
- Establish relationships which would allow instream habitat requirements to be predicted for other Wellington rivers and streams without the need for habitat surveys (i.e. to consider using the collected information and applying it as a regional method (Volume A, Section 10.3.3.4)).

Twelve reaches in 10 Wellington rivers were surveyed using IFIM (Figure 40). The rivers were generally "clean", had gravel beds, drained native forest catchments and had well defined riffle-pool structures. Physical habitat was considered to be the critical factor.

Fig 40: Location of the instream habitat survey reaches in 12 reaches of Wellington rivers and streams. (source: Jowett 1993)



13.1 Instream Management Objectives

The report by Jowett (1993) gives an example of establishing minimum flow requirements based on the following two habitat quality guidelines:

(1) A basic minimum amount of water is retained in all rivers. For example, habitat quality guidelines could require the retention of at least 13 percent of the water surface width at the minimum flow as habitat suitable for food production and, in trout rivers, at least 6.5 percent of the area as habitat suitable for adult brown trout.

(2) There should be a limit to the amount of change caused by flow modification to any river. For example, no flow modification should reduce the existing food producing or brown trout habitat at low flow by more than 33 percent.

The percentages used in the first habitat quality guideline are those which are exceeded by 85 percent of rivers in the "100 rivers" database. This percentage figure is arbitrary, based on a "national perspective". The percentage figure used in the second guideline is also arbitrary. The scientists involved in developing these guidelines readily acknowledge that the figures used are arbitrary. Variation to the arbitrary figures used in these guidelines will affect flow recommendations.

Jowett (1993) also developed regional formula for the calculation of minimum flow requirements for other rivers in the Wellington Region. These regional formula are derived from the relationship between flows and catchment characteristics for the rivers already studied. The two regional formula use the mean annual low flow to calculate minimum flows to maintain each of the two habitat quality guidelines identified above.

13.2 Modelling results

Figures 41 and 42 show examples of the types of information that the Weighted Usable Area method (a measure of habitat) can provide in surveyed rivers.

Fig 41: Variation in the weighted usable area of adult brown trout habitat with flow in the Wellington rivers (source: Jowett 1993)

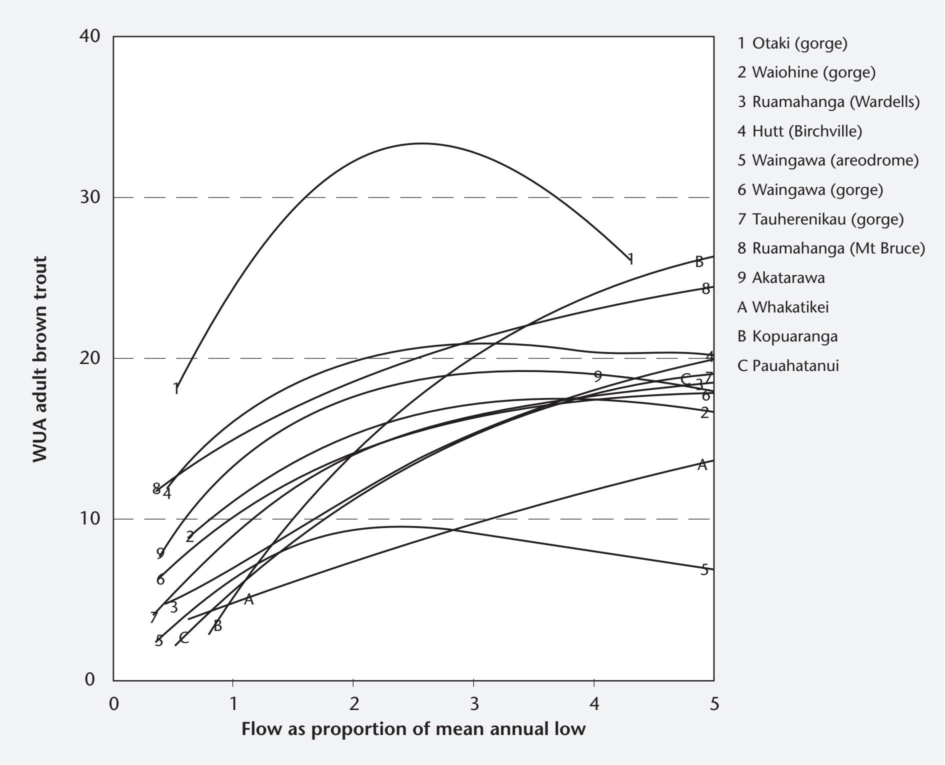
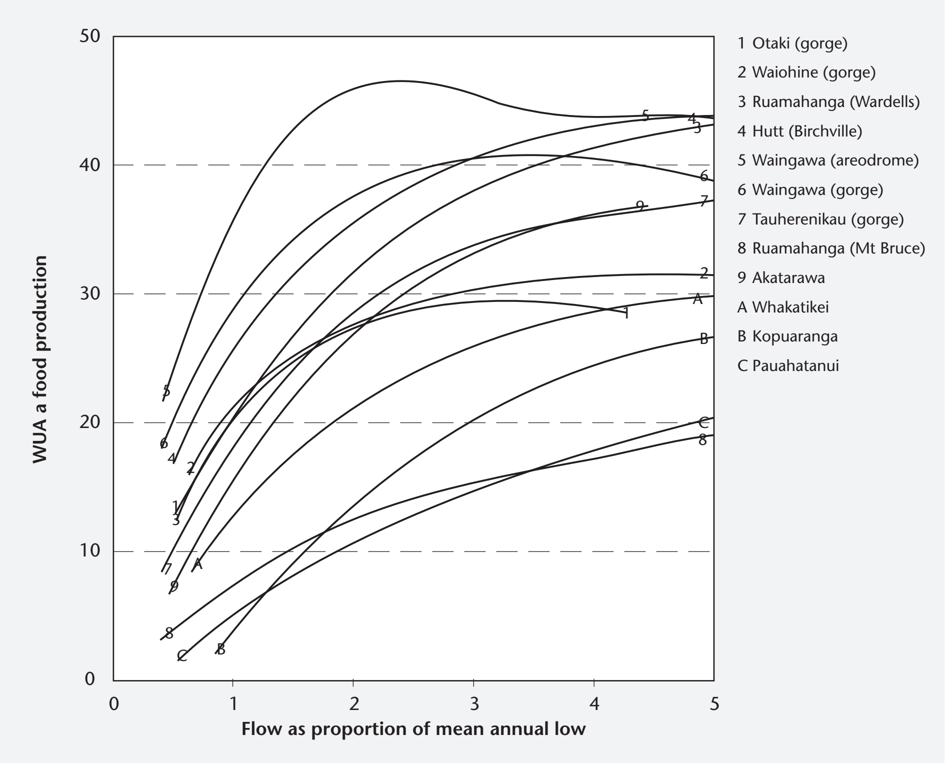


Fig 42: Variation in the weighted usable area of food-producing habitat with flow in the Wellington rivers (source: Jowett, 1993)



Jowett's study indicated the variation of instream habitat with flow showed a similar pattern in all rivers. Habitat increased parabolically with flow, reaching an optimum at median or lower flows for the larger rivers and above median for the smaller. Thus, minimum flow assessments based on habitat guidelines suggest that "minimum flows" should be relatively higher in smaller rivers.

Minimum flow requirements for adult trout habitat were related to the average depth and mean annual low flow, whereas the flow requirements for food producing habitat were related only to average water velocity. Table 12 shows minimum flow requirements for maintaining adult brown trout and food producing habitat by either retaining a percentage of the water surface as usable habitat or retaining two thirds of the habitat available under natural flows.

Minimum flow assessments were related to mean annual low flow, median flow, average water velocity, catchment area, and average river width. The relationship with mean annual low flow explained 88 percent of the variation in low flow assessments and provides a convenient method of estimating minimum flow requirements for habitat maintenance.

Table 12
Minimum flow requirements using habitat guidelines (source: Jowett 1993)

Reach	Food producing habitat (expressed as % of annual low flow)		Adult brown trout habitat (expressed as % of annual low flow)		Mean Annual flow
	13% WUA	2/3 WUA	6.5% WUA	2/3 WUA	(l/s)
Otaki (Gorge)	50	54	2	40	3792
Waiohine (Gorge)	42	46	34	42	3054
Ruamahanga (Wardells)	50	54	92	44	1933
Hutt (Birchville)	27	46	8	36	2009
Waingawa (aerodrome)	13	48	107	63	1180
Tauherinikau (gorge)	59	54	69	59	5240
Ruamahunga (Mt Bruce)	207	56	2	13	4730
Akatarawa	79	63	29	48	1132
Whakatikei	94	57	169	34	318
Kopuaranga	192	82	117	80	235
Pauatahanui	249	67	119	71	88

13.3 Wellington Regional Council (WRC) perspective

The WRC has commented on the use of Jowett's report for river flow and water allocation planning purposes. During the preparation of the Proposed Regional Freshwater Plan for the Wellington Region (1997), the IFIM data provided some useful information about aquatic habitat in relation to flows for the water bodies surveyed. For these rivers, the IFIM method was not the only consideration for deriving minimum flows. The IFIM data was complemented by other technical data, and information on other values and uses of rivers before minimum flows were set.

At the time of finalising these guidelines, the Wellington Freshwater Plan was going through the statutory process. We are therefore unable to comment on how conflict was resolved in this case.

13.4 References

Jowett, I.G. 1993. Minimum flow assessments for instream habitat in Wellington rivers. *New Zealand Freshwater Miscellaneous Report 63*. Report to Wellington Regional Council.

Hayes, J.W. 1993. Minimum flow assessments for instream habitat in the Waikanae River. *New Zealand Freshwater Miscellaneous Report 134*. Report to Wellington Regional Council.

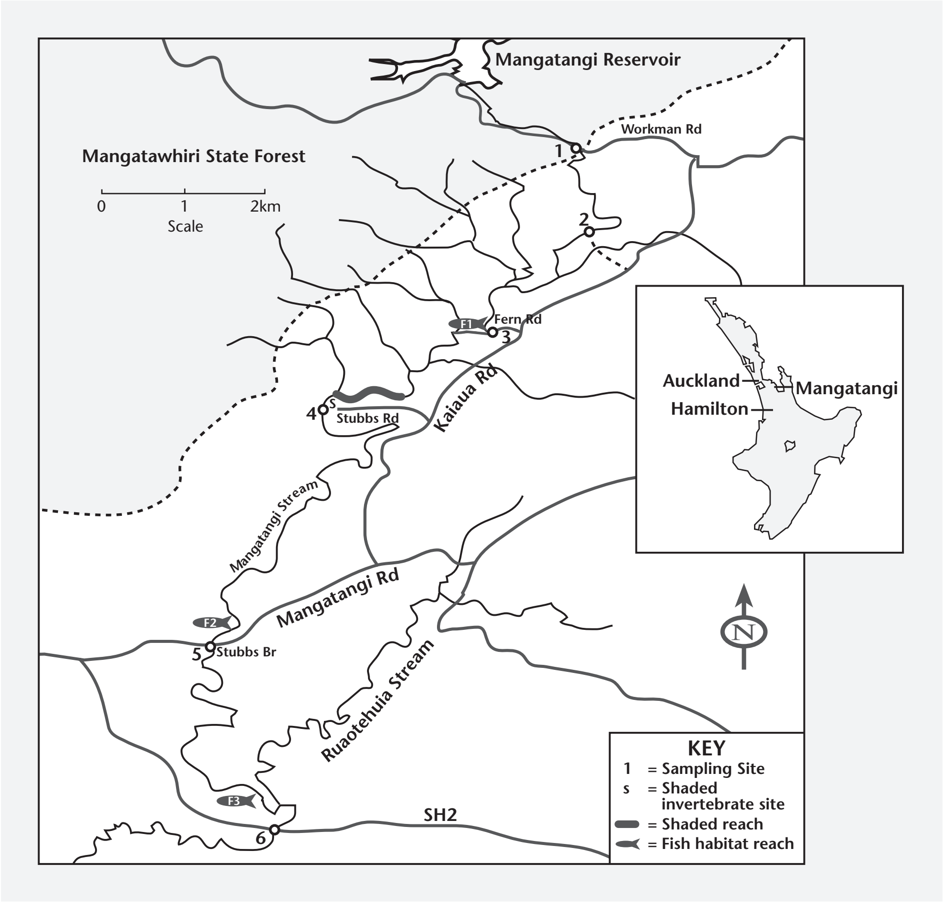
14. Use of Riparian Management as a Remedying Measure

This worked example is based on an investigation carried out by NIWA in 1992 for Auckland Regional Council Services (now Watercare Services Ltd).

14.1 Background

The Mangatangi Stream originates in the Auckland Regional Park. Upstream of a water supply dam the Mangatangi Catchment is covered in regenerating native bush. Two kilometres downstream of the dam, the stream leaves the native bush and enters developed pasture land. Downstream of the native-bush boundary there is little to no riparian cover with the exception of a 1.3 km reach (see Figure 43).

Fig 43: Map of Mangatangi Stream from the reservoir to State Highway 2 showing sampling sites (source: Cooke et al 1992)



The residual flow from the dam is approximately a 1:20 year summer low flow. The stream is very shallow, with a depth averaging 25-38 cm.

As stated in Section 10.2 of Volume A, there are three components to a Flow Regime Requirement for ecological values:

- Minimum flow for habitat
- Minimum flow for water quality
- Flow variability

In this case the Flow Regime Requirement issues relate to:

- Loss of physical habitat area (i.e. minimum flow for habitat).
- Periphyton growth is excessive, smothering the bed, causing diurnal variations in dissolved oxygen (DO) and low DO levels at night (a flow variability issue).
- Water temperatures become very high, in excess of 26°C (i.e. a minimum flow for water quality).

14.2 Instream management objectives

Using the terminology developed in these guidelines, the Instream Management Objectives are:

- A suitable habitat for trout should be maintained. Given the close proximity of the stream to Auckland city the trout fishery of the Mangatangi Stream was considered significant by anglers.
- Dissolved oxygen should not fall below 80 percent in order to protect normal ecosystem functions.
- Temperature should not rise above 26°C (maximum/mean daily), in order to protect fish and maintain ecosystem functions.

In this case, as the following discussion shows, temperature was the critical factor for achieving the Instream Management Objective.

14.3 Technical assessment methods used to set the Flow Regime Requirement

Three technical assessment methods were used to set Flow Regime Requirements, reflecting the *Instream Management Objectives*:

- IFIM modelling was used to determine suitable amounts of habitat.
- Dissolved oxygen modelling, using estimates of periphyton growth under different management regimes, was used to assess whether dissolved oxygen concentrations can be managed more effectively.
- Temperature modelling was undertaken to assess the effects of increased residual flows and riparian shading.

14.3.1 IFIM modelling

Habitat was modelled at three locations downstream of the dam (Figure 43). At all three sites the habitat area (estimated weighted usable area) for brown trout either declined or remained static with an increase in flow (Figure 44). The area suitable for trout food production increased significantly with increasing flows at Fern Road (Figure 45) but the increase at the other two sites was small.

Fig 44: Effect of changing compensation flow on the weighted usable area available for brown trout (source: Cooke et al 1992)

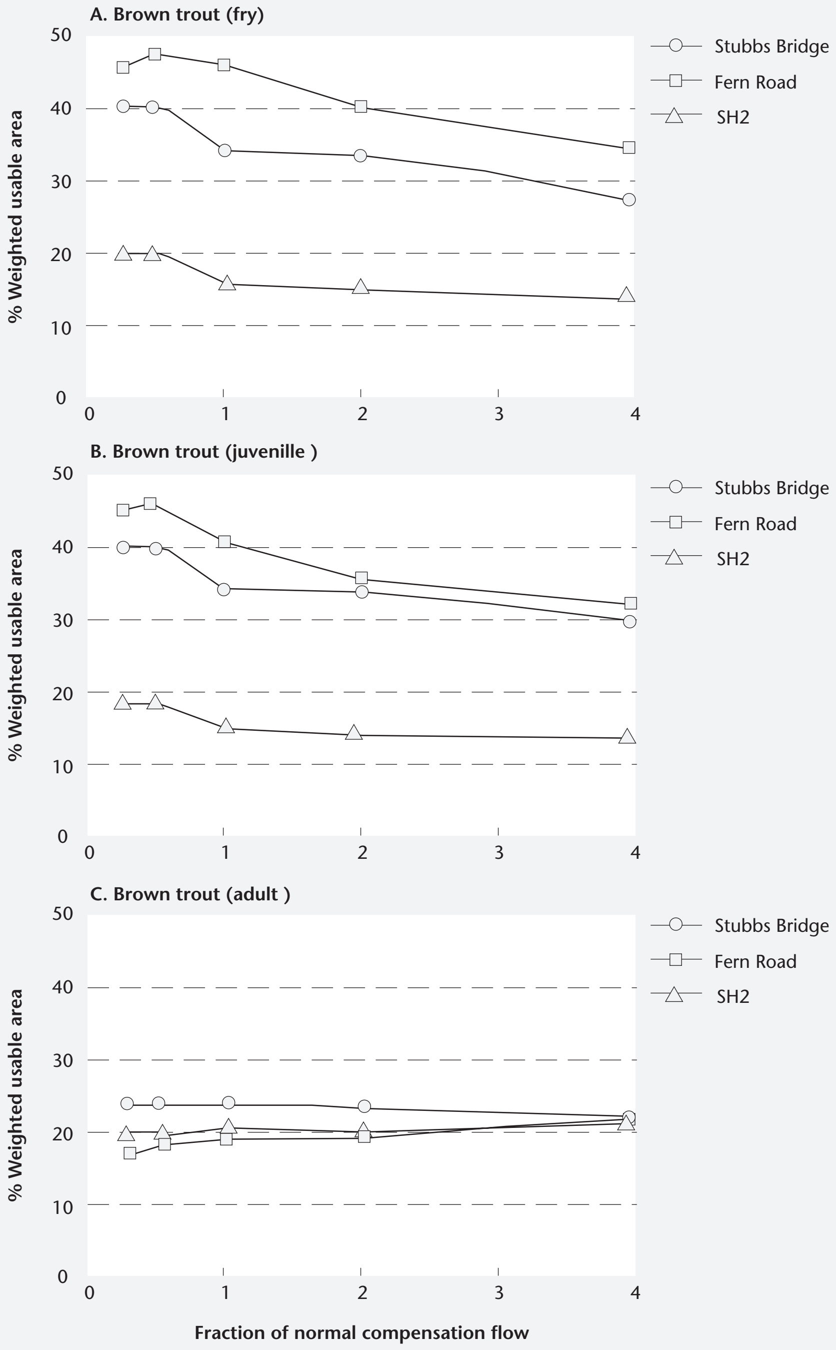
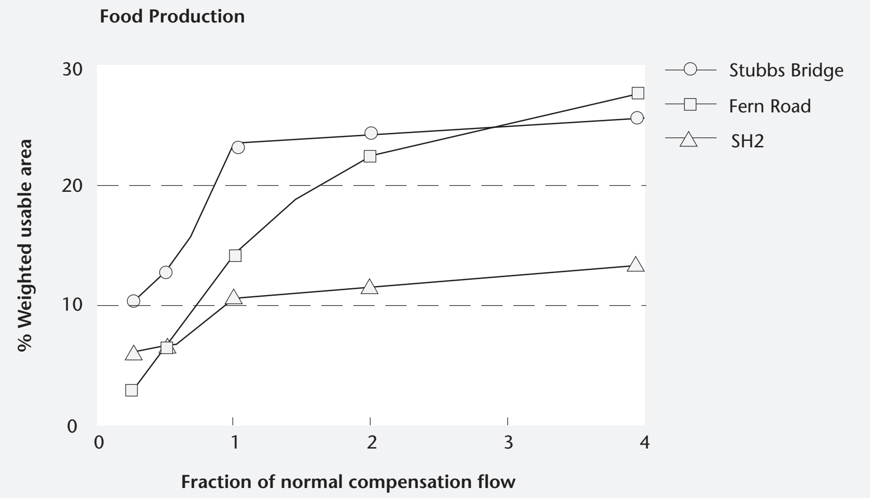


Fig 45: Effect of changing compensation flow on the weighted usable area available for food producing species (source: Cooke et al., 1992)



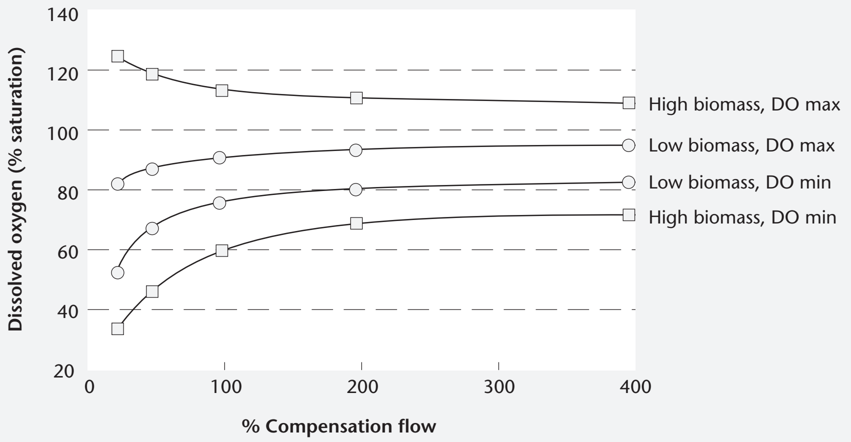
The IFIM modelling exercise shows that increasing flows will not result in an increase in suitable habitat for trout. A Flow Regime Requirement for brown trout habitat equates to the current residual flow.

14.3.2 Dissolved oxygen (DO)

Downstream of the dam, there were extensive periphyton growths, which caused a diurnal variation in DO and low night-time DO concentrations. Modelling was carried out to assess whether DO could be more effectively managed by controlling periphyton growths or by increasing residual flows.

The results of the flow modelling exercise are presented in Figure 46, for two situations; high periphyton growth (the current situation) and low periphyton growths. An increase in residual flow will have little impact on minimum DO levels, i.e. would not achieve the Instream Management Objective. The DO “problem” was caused more by nutrient enrichment than low flows.

Fig 46 DOFLO predictions of daily minimum and maximum summer DOs at different compensation flows under conditions of high and low periphyton biomass (source: Cooke et al., 1992)



Scientists considered using periodic releases from the dam, to flush periphyton from the stream. At the time of the study there was insufficient information to establish a flow regime for flushing periphyton and the scientists were not prepared to make a recommendation on a flow regime that incorporated "flushing flows". Research carried out since 1992 may provide the basis for setting a "flushing flow" (e.g. the concept of FRE$_3$ - see Section 1.2.1.7).

The modelling concluded a suitable Flow Regime Requirement for DO is the current residual flow because (i) an increase in flow would not increase DO levels, and (ii) a decrease in flow would reduce DO levels.

14.3.3 Temperature

Elevated water temperatures during summer are of concern. The maximum temperatures (greater than 26°C) are too high for trout and are likely to adversely affect native fish and invertebrates. The high temperatures indirectly place stress on other aquatic life by increasing periphyton growths, smothering habitat and lowering DO levels.

Using the terminology developed in the guidelines, an Instream Management Objective was set for temperature; temperature should not exceed 26°C.

Temperatures during summer can exceed 26°C at present low flows. Investigations were made into whether the Instream Management Objective for temperature could be met by (i) increasing residual flow, i.e. setting a new Flow Regime Requirement and/or (ii) increasing riparian shading.

A controlled release experiment was carried out to study the effects of increased flows on water temperature, but the meteorological conditions were largely unfavourable (i.e. unusually low air temperatures for mid-summer conditions). As a consequence, the results could not be extrapolated and confidently used to empirically predict mid-summer maximum water temperatures. A mathematical model was therefore used to make these predictions. The results are presented in Figure 47.

Fig 47: Predicted water temperature for a "slug" of water leaving site 4 at 0800 in midsummer and travelling 12 km (source: Cooke et al., 1992)

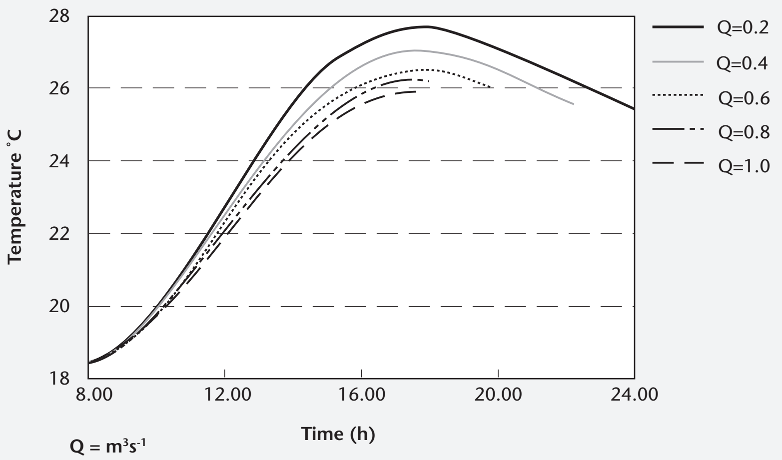
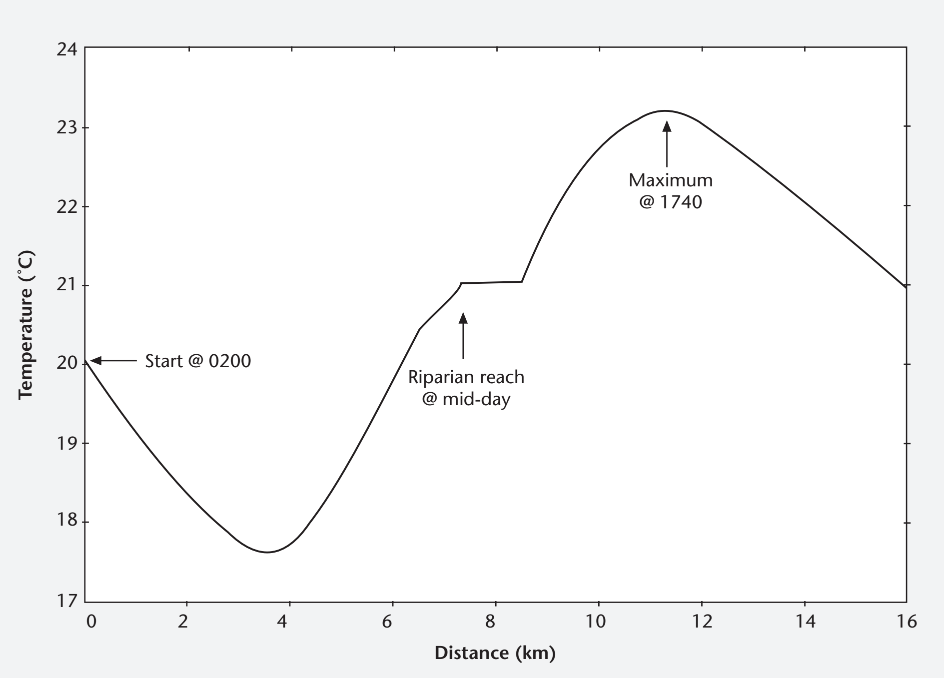


Figure 47 shows that a reduction in low flows causes temperatures to increase and that low flows need to be at least doubled to reduce temperatures below 26°C. Specifically, the Flow Regime Requirement is 0.9 m^3s^{-1} to meet the Instream Management Objective for temperature.

In investigating the effects of riparian shading, scientists observed a 1.3 km shaded stretch significantly reduced water temperatures in the stream. At the time of the study, the effects of riparian shading on water temperature were not well understood, but the scientists used the available information to develop a mathematical model for assessing the impacts of riparian shading on water temperature. The modelling confirmed the short stretch of riparian cover helped reduce stream water temperatures (Figure 48).

Fig 48: Predicted water temperature for a "slug" of water realeased at 0200 from the ARC flume at 0200 7th Feb (starting temperature 20.2°C). (source: Cooke et al., 1992)



The results of the shading-temperature modelling exercise are presented in Figure 49. Three scenarios are modelled:

- "Riparian 1": 100 percent shading for the first kilometre downstream of the native bush, zero shading from 1-6 km, 50 percent shading from 6-7 km and zero thereafter.
- "Riparian 2": 50 percent shading for the first kilometre downstream of the native bush, zero shading from 1-6 km, 50 percent shading from 6-8 km and zero thereafter.
- "Riparian 3": 100 percent shading for the first two kilometres downstream of the native bush, zero shading from 2-6 km, 100 percent shading from 6-8 km and zero thereafter.

Fig 49: Predicted stream temperature as a function of travel time with alternative riparian shading options. (source: Cooke et al., 1992)

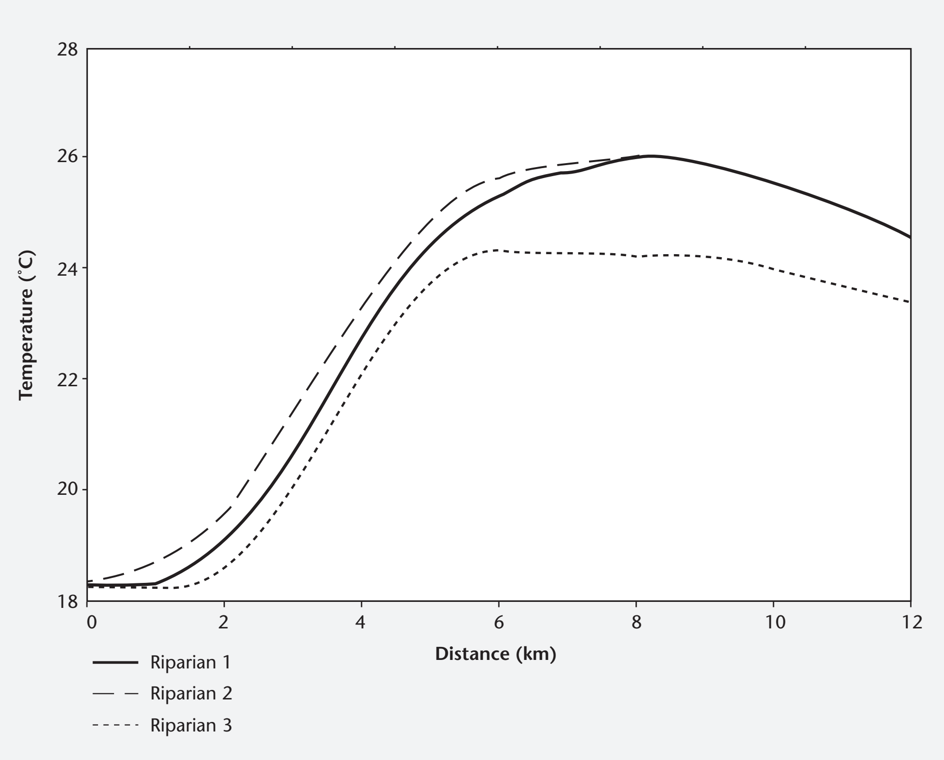


Figure 49 shows that even limited riparian shading (Riparian 2) will keep water temperatures below the Instream Management Objective level of 26°C, so riparian shading has potential as a remediation measure for this worked example. In addition, shading will reduce periphyton growth and increase diversity of invertebrate species and will therefore assist in achieving other Instream Management Objectives, e.g. for dissolved oxygen.

14.4 Conclusions

For ecological values, flow regime requirements need to address:

1. Flow ***variability***.
2. Flows for ***water quality***.
3. Flows for ***habitat.***

- For brown trout habitat, the current residual flow is a suitable Flow Regime Requirement.
- Diurnal variation in DO, caused by periphyton growth, is resulting in DO levels below that set for the Instream Management Objective. Any further reduction in flow regime would be detrimental to river water

quality. Controlled releases (i.e. flushing flows) would be one way of controlling periphyton growth and therefore DO, but there is insufficient information available for a robust recommendation to be made on a suitable Flow Regime Requirement.

A Flow Regime Requirement for flow ***variability*** (point 1 above) was not set. There was insufficient information to set a Flow Regime Requirement for flow variability, and riparian shading and/or flushing flows could be used to help reduce periphyton. Recent research has suggested a suitable flushing flow may be developed using the FRE_3 (Section 1.2.1.7).

An increase in flow, without controlled releases, will not greatly increase DO concentrations, but a decrease in flow will reduce DO concentrations. The current residual flow is an appropriate Flow Regime Requirement for DO, a critical consideration for ***water quality*** (point 2 above).

- The Instream Flow Requirement for temperature (i.e. ***water quality***) means a substantial increase of current residual flows are required. But riparian shading shows considerable promise as a means of controlling water temperature and achieving the Instream Management Objective for water temperature (***water quality***, point 2 above). In addition, shading would reduce periphyton growths and could increase minimum DO levels.

Remediation seems an appropriate solution for this situation. The most promising strategy for achieving the Instream Management Objectives is to plant shade trees at critical reaches along the stream and set the Flow Regime Requirement at the current residual flow. Riparian planting will enable the temperature component of the Instream Management Objective to be met and assist in achieving the Instream Management Objective for dissolved oxygen.

At the time of finalising the guidelines, this issue was being discussed in pre-hearing meetings. We are therefore unable to comment on how the conflict between instream and out-of-stream values were resolved in this case.

14.5 References

Cooke, J.C., Cooper, A.B., McBride, G.B., Smith, C.M. 1992. Residual flow issues in the Mangatangi Stream. Consultancy Report No. ARC042, Water Quality Centre, National Institute of Water & Atmospheric Research Ltd., Hamilton, New Zealand. 92p.

McBride, G.B., Cooke, J.B., Cooper, A.B., Smith, C.M 1994. Optimising habitat in a stream impounded for water supply. In Restoration of Aquatic Habitats. Selected papers form the second day of the Limnological Society 1993 Annual Conference. Department of Conservation. P111-123.

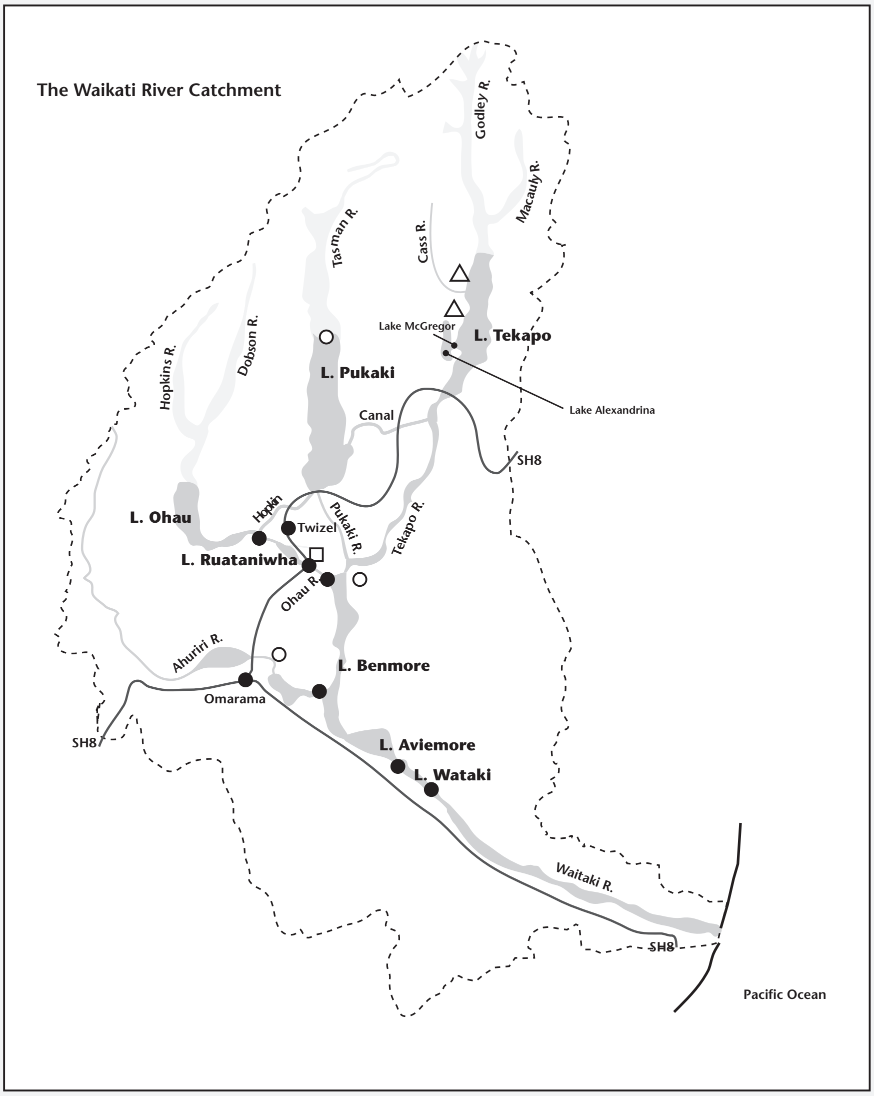
15. Habitat Case Study: Remediation and Mitigation

As discussed in these guidelines, the RM Act recognises that adverse effects can occur, and in some cases, remedying and mitigating these effects is appropriate (Volume A, Section 5.2.3). Below is an example of a remediation and mitigation measure negotiated before the passing of the RM Act. In specific situations this type of approach may be appropriate to use to meet an Instream Management Objective.

15.1 Background

The braided rivers and wetlands of the Upper Waitaki Catchment are habitat to some of New Zealand's unique wildlife. The wide shingle river beds of Tekapo, Ohau, Ahuriri Rivers are some of the best remaining examples of braided rivers in the southern hemisphere (Figure 50).

Fig 50: Location of the Waitaki Catchment and Project River Recovery (source: Robertson et al., 1983)



KEY

SITES OF RIVER AND WETLAND HABITAT WORK UNDERTAKEN TO DATE

● Hydro Electric Power Station
○ River weed control
□ Wetland creation, predator barriers and aviary construction
△ Wetland improvement and predator barriers

The water resource of the Waitaki area is of national importance for power generation. The Waitaki area also provides a significant water resource for irrigation.

Hydro development substantially reduced aquatic habitat in the Upper Waitaki Catchment. Change to natural flows of water (damming, diversion and water extraction) caused a reduction in shallow water habitat for braided river birds, particularly the endangered black stilt. Reduced flood sizes and frequencies allowed weeds to invade riverbeds further reducing habitat. These changes threatened the survival of some bird species, particularly the black stilt, which is of conservation concern.

Those with interests in the Waitaki catchment met and discussed their individual Instream Management Objectives with ECNZ. This case study focuses on the successful outcomes negotiated with ECNZ and other water users to protect the conservation values of the Upper Waitaki Catchment. Other values were catered for in the negotiations but are not discussed in this example.

Through consultation it was decided that a suitable flow regime could not be established to protect all conservation values. Some mitigation and remediation measures were also needed to help meet the Instream Management Objective.

15.2 Instream Management Objective

Using terminology developed in the guidelines, the Instream Management Objective for this conservation case study seems to be: to create and enhance wetland habitat at least as great as that which was lost through the Waitaki hydro-power development. In resolving competition between instream and out-of-stream values, the approach adopted here was to set a “bottom line” of the survival of the black stilt.

15.3 Project River Recovery

Project River Recovery was set up to achieve the Instream Management Objective. The project is possible through an agreement between DoC and ECNZ. ECNZ has the right to use water in the Waitaki system for power generation, and this has resulted in less water in some river beds than previously. In return, ECNZ provides substantial funding to help control exotic vegetation, to enhance and create swamps and ponds for wading birds and to contribute to a captive breeding facility for black stilt (Figure 50).

The majority of Project River Recovery’s activities take place in areas where hydro-power development has had an impact on natural habitat (i.e.

remediation activities). An exception is the Ahuriri River where ECNZ does not extract water (Figure 50). In the Ahuriri River area, Project River Recovery is controlling weeds and creating wetland to replace habitat which was lost elsewhere.

This case study is an effective example of mitigation, i.e. mitigation measures are taking place out-of-stream in an unaffected area to help offset the effects of destruction in other areas (Volume A, Section 10.4).

15.4 Conclusions

This case study shows that in certain circumstances, both remediation and mitigation can be used as an appropriate means of achieving an Instream Management Objective.

15.5 References

Robertson, C.J.R; O'Donnell, C.F.J; Overmars, F.B. 1983. Habitat requirements of Wetland Birds in the Ahuriri River Catchment New Zealand. New Zealand Wildlife Service.

Appendix I

Flow recording sites in New Zealand for which more than 5 years of flow data on archive. Source: Walter, 1994.

Site No	River	Site Name	Map Reference (NZMS 260)	Authority	Begin Date (year/month/day)	End	Archived
NORTHLAND							
802	Selwyn Swamp	Big Flat Rd	N 4:265981	NRC	650826		NR
1310	Whangatane	Donald Rd	O 4:347781	NIWA-Whr	601109	800509	N
1313	Tarawhataroa	Pukepoto Rd	O 4:343764	NIWA-Whr	710923	800509	N
1314	Awanui	Waikuruki	O 4:344776	NIWA-Whr	720502	800509	N
1316	Awanui	School Cut	O 4:352761	NIWA-Whr	580124		N
1330	Awanui	Slackline	O 4:315774	NIWA-Whr	720225	800509	N
1903	Oruru	Saleyards	O 4:575801	NIWA-Whr	881215		N
1909	Peria	Honeymoon Valley	O 4:558755	NIWA-Whr	740725	810409	N
3409	Waipapa	Pungaere Rd	P 5:915670	NRC	750918	810304	NR
3412	Rangitane	Tubbs	P 5:995674	NRC	770714		NR
3419	Waipapa	Intake 6	P 5:917671	NIWA-Whr, NRC	821201	880907	NR
3503	Puketotara	Backblocks	P 5:916615	NRC	750909	890131	NR
3506	Maungaparerua	Tyrees Ford	P 5:913625	NIWA-Whr	671122		N
3518	Waiwhakangarongaro	Baxters	P 5:922599	NIWA-Whr	800724	880907	N
3519	Waipapa	Diversion Outlet	P 5:909593	NIWA-Whr	820416	880204	N
3707	Waiaruhe	Puketona	P 5:981549	NRC	840201		NR
3710	Whangai	Wiroa Rd	P 5:887583	NIWA-Whr	791005	840815	N
3722	Waitangi	Wakelins	P 5:061577	NIWA-Whr	790214		N
3806	Kawakawa	SHBr	P 5:072466	NIWA-Whr	611216	680405	N
3819	Waiharakeke	Willowbank	P 5:034446	NRC	670202		NR
3829	Tiruhanga	D/S County Intake	P 5:103466	NRC	890321		R
3835	Veronica Channel	Opua	Q 5:127537	NRC	900426		R

4901	Ngunguru	Dugmores Rock	Q 7:378164	NRC	690822		NR
5513	Glenbervie	Quarry	Q 6:327163	NIWA-Whr	761230	870105	N
5515	Glenbervie	Pines	Q 6:334167	NIWA-Whr	790405	900709	N
5516	Glenbervie	Log Br	Q 6:329164	NIWA-Whr	790404	900709	N
5519	Waiarohia	Russell Rd	Q 7:297090	NIWA-Whr	570830	680101	N
5526	Kirikiri	Bypass Culvert	Q 7:291070	NRC	791102	810217	NR
5527	Waiarohia	Lovers Lane	Q 7:298076	NRC	791017		NR
5528	Raumanga	Bernard St	Q 7:295067	NRC	791030		NR
5538	Hatea	Whareora Rd	Q 6:311101	NRC	860630		NR
5539	Hatea	Town Basin	Q 7:307076	NRC	860107		R
5541	Whangarei Harbour	Port	Q 7:328040	NRC	890829		R
5801	Whangarei Harbour	Marsden Pt	Q 7:453952	NRC	890619		R
5901	Ruakaka	Flyger Rd	Q 7:374915	NRC	840319		NR
5911	Waiwarawara	Wilsons Dam	Q 7:385883	NIWA-Whr	911023		N
6004	Ahuroa	Rowntrees	Q 8:378777	NIWA-Whr	690228	760101	N
6007	Waionehu	McLean Rd	Q 8:421759	NRC	821110		NR
6014	Ahuroa	Durham Rd	Q 8:378730	NRC	810429		NR
6015	North	Applecross Rd	Q 7:379838	NRC	821111		NR
6016	Waihoihoi	St Marys Rd	Q 8:395763	NRC	840127		NR
6018	Ahuroa	Braigh	Q 8:379768	NRC	830829		NR
45903	Topuni	Old North Rd	Q 8:417542	NIWA-Whr	761221	860522	N
46602	L Kanono	Kanono Outlet	Q 9:139367	NRC	770216	820524	NR
46609	Mangere	Kara Weir	Q 7:226093	NIWA-Whr	750424	930805	N
46611	Kaihu	Gorge	P 7:727042	NRC	700302		NR
46612	Kaihu	Maropiu	P 7:770000	NIWA-Whr	581002	710726	N
46618	Mangakahia	Gorge	P 6:878189	NIWA-Whr	601201		N
46625	Hikurangi	Moengawahine	P 6:050167	NRC	600409		NR
46626	Mangakahia	Titoki Br	P 7:059071	NRC	830228		NR
46627	Waiotu	SHBr	Q 6:222290	NRC	871020		R
46632	Whakapara	SHB	Q 6:262284	NRC	560929		NR

46641	Waipao	Draffins Rd	Q 7:127077	NRC	790622		NR
46644	Wairua	Purua	Q 6:149159	NRC	600321		NR
46645	Kokopu	McBeths	Q 7:184077	NIWA-Whr	770629	860805	N
46646	Mangere	Knights Rd	Q 6:143109	NRC	830208		NR
46647	Wairua	Wairua Br	P 7:097072	NRC	610906		NR
46651	Manganui	Permanent Station	Q 7:111816	NRC	600520		NR
46654	Northern Wairoa	Kirikopuni	P 7:020959	NRC	80		R
46655	Northern Wairoa	Dargaville	P 7:894841	NRC	79		R
46658	Northern Wairoa	Ruawai	P 8:023626	NIWA-Whr	690828	740615	N
46660	Puketurua	Puketitoi	P 6:075151	NIWA-Whr	640101	860805	N
46661	Puketurua	Backwater	P 6:075152	NIWA-Whr	680121	760121	N
46662	Pukewaenga	Conservation	P 6:083139	NIWA-Whr	660512	800924	N
46663	Pukeiti	Riddolls	P 6:083132	NIWA-Whr	660701	800924	N
46674	Mangahahuru	County Weir	Q 6:295170	NRC	681215		NR
46675	Northern Wairoa	Tangiteroria	P 7:046973	NRC	79		R
46684	Northern Wairoa	Pukehuia	P 7:017888	NRC	79		R
47527	Opahi	Pond	P 5:764436	NIWA-Whr	660203	940124	N
47538	Taheke	Morungas Reach	O 6:699369	NIWA-Whr	881215	940124	N
47540	Waikaka	Totara trees	P 5:825409	NRC	891110		R
47703	L Omapere	Rocky Outcrop	P 5:818483	NIWA-Whr	690423	760428	N
47804	Waipapa	Forest Ranger	P 5:730583	NIWA-Whr	750917		N
48015	Mangamuka	Gorge	O 5:564668	NIWA-Whr	760331	940120	N
1046651	Opouteke	Suspension Br	P 6:891114	NRC	841213		NR

AUCKLAND

6302	Slipper Lake		R 8:576576	ARC	900110		NR
6501	Tamahunga	Quintals Falls	R 9:662400	ARC	780223		NR
6602	Glen Eden	Hitchings Farm	R 9:626355	NIWA-Akd	870623		N
6806	Mahurangi	College	R 9:586319	ARC	820611		N
6922	Awana	Bush Edge	T 8:320536	NIWA-Akd	870508		N
7109	Waiwera	McCathys Falls	R10:591154	ARC	800129	880511	NR

7202	Orewa	Kowhai Ave	R10:587104	ARC	760127		NR
7602	Wairau	Alma Rd	R10:673904	NIWA-Akd	621128	790402	N
7604	Wairau	Motorway	R11:666898	NIWA-Akd	780317		N
7607	Wairau	Chartwell	R11:652894	NIWA-Akd	800417	860715	N
7805	Rangitopuni	Walkers	R10:550948	ARC	750515		NR
7811	Oteha	Days Br	R10:618953	ARC	791213		NR
7835	Rangitopuni	Deacon Rd	R10:512937	NIWA-Akd	800110	861007	N
7837	Rangitopuni	Rols	R10:518952	NIWA-Akd	800227	861007	N
7907	Swanson	Woodside Reserve	R11:543861	ARC	931116		NR
8001	Rewarewa	Gardeners Ave	R11:597752	NIWA-Akd	660101	760630	N
8202	Pakuranga	Richardsons	R11:801756	NIWA-Akd	710413	800617	N
8203	Manukau	Somervilles	R11:823746	NIWA-Akd	690613	870113	N
8204	Otara	Bond St Br	R11:779691	ARC	781026	930406	NR
8207	Pakuranga	Moonys Br	R11:802765	ARC	790920		NR
8209	Pakuranga	Sunnyhills	R11:788756	ARC	880803		NR
8514	Wairoa	Dam	S12:987532	ARC	760213		NR
8516	Wairoa	Tourist Rd Br	S11:931633	ARC	790101		NR
8521	Wairoa	Cosseys Dam	S12:976572	ARC	790709		NR
8529	Mangawheau	Weir	S12:942531	ARC	880615		NR
8604	Orere	Bridge	S11:097682	NIWA-Akd	780629		N
43602	Waitangi	SHBr	R12:655401	NIWA-Akd	660330		N
43705	Mauku	Swede	R12:700453	ARC	770202	820531	NR
43803	Papakura	Great Sth Rd	R11:800614	ARC	690616		NR
43805	Papakura	Fitzpatrick Rd	R11:864651	NIWA-Akd	700721	771219	N
43807	Puhinui	Upstream Dropstr	R11:769660	ARC	781206		NR
43810	Maketu	Rimu Stand	R12:875494	NIWA-Akd	701223	760531	N
43811	Patumahoe	Railway Culvert	R12:737439	ARC	760929		NR
43829	Ngakaroa	Mill Rd	R12:855432	ARC	800328		NR
44102	Upper Nihotupu	Dam	Q11:497711	ARC	871208		R

44103	Lower Nihotupu	Dam	R11:542698	ARC	880830		R
44202	Upper Huia	Dam	Q11:474696	ARC	860911		R
44604	Waitakere	Dam	Q11:466770	ARC	881222		R
45301	Huapai	NZ Particle Board	Q10:487905	ARC	770520		NR
45311	Kaipara	Waimauku	Q10:436919	ARC	781009		NR
45315	Kumeu	Maddren	Q10:498908	ARC	831202		NR
45326	Ararimu	Old North Rd	Q10:453943	ARC	831214		NR
45346	Waikoukou	Longlands	Q10:459954	NIWA-Akd	850705		N
45347	Wharauroa	Moffats	Q10:435945	NIWA-Akd	850717	930120	N
45401	Waitoki	Pebblebrook Confl	R10:503097	ARC	770117	841218	NR
45407	Kaukapakapa	Oak Hill	Q10:474069	ARC	880418	930401	NR
45414	Kaukapakapa	Rapsons Rd	Q10:465068	ARC	910520		NR
45504	Makarau	Coles	Q10:459150	NIWA-Akd	850331		N
45702	Waiwhiu	Dome Shadow	R 9:569376	NIWA-Akd	671123		N
45703	Hoteo	Gubbs	Q 9:460340	ARC	770804		NR
1043408	Mangatawhiri	Dam	S12:016551	ARC	650923		NR
1043455	Mangatawhiri	L Mangatawhiri Weir	S12:027497	ARC	640427		NR
1543473	Mangatangi	Dam	S12:067518	ARC	780615		NR
1543479	Mangatawhiri	Moumoukai North	S12:021547	ARC	680101		NR
1543480	Mangatawhiri	Moumoukai Central	S12:020546	ARC	671215		NR
1543481	Mangatawhiri	Moumoukai South	S12:020543	ARC	681230		NR

WAIKATO

9009	Waitakaruru	Quarry Rd Weir	S12:162330	EW	800815		NR
9101	Waitoa	Whakahoro Rd	T13:388067	EW	520122	721128	NR
9106	Piako	Kaihere Ferry	T13:327272	EW	640819	840412	NR
9108	Piako	Whakahoro Rd	T13:317048	EW	5203	710401	NR
9112	Waitoa	Waharoa Control	T14:518786	EW	840116		NR

9114	Waitoa	SH26, Waitoa	T14:427972	EW	900321		NR
9117	Waitoa	Paeroa Tahuna Rd Br	T13:372083	EW	720607	840120	NR
9140	Piako	Paeroa Tahuna Rd Br	T13:318068	EW	720703		NR
9144	Piako	Maukoro Landing Rd	T13:324161	EW	810316		NR
9175	Piako	Kiwitahi	T14:398857	EW	800423		NR
9177	Waitakaruru Trib	Scotsmans Valley	T14:302762	NIWA-Ham	801222	870216	N
9179	Waitoa	Mellon Rd	T13:425047	EW	860502		NR
9181	Carters Canal	South Flume	T13:384194	EW	891215		NR
9203	Waihou	Puke	T13:448238	EW	590322		NR
9205	Waihou	Te Aroha Br	T13:494026	EW	6501		NR
9209	Waihou	Tirohia	T13:437148	EW	530519		NR
9212	Waihou	Kopu	T12:378425	EW	560127	841004	NR
9213	Ohinemuri	Karangahake	T13:506172	EW	560404		NR
9223	Waihou	Shaftesbury	T14:549934	EW	820310	871012	NR
9224	Waihou	Okauia	T14:602756	EW	820323		NR
9228	Waiorongomai	Old Quarry	T13:573010	NIWA-Ham	701222		N
9231	Waihou	Whites Rd	T15:572500	EW	771209	830224	NR
9301	Kauaeranga	Smiths	T12:404461	EW	590201		NR
9415	Thames	Tararu	T12:343496	EW	900507		NR
9610	Waiomu	Days	T11:353608	EW	841128	921003	NR
9701	Tapu	Tapu-Coroglen Rd	T11:332658	EW	910701		NR
10201	Waiau	E309 Rd Ford	T11:357866	EW	910704		NR
10202	Pukewhau	Tiki Quarry Rd	T11:358873	EW	931223		NR
11310	Opitonui	Dstm Awaroa Confluence	T11:428883	EW	910607		NR
11605	Mahikarau	E309 Rd	T11:411793	EW	870922		NR
11807	Waiwawa	Rangihau Rd	T11:488705	EW	910703		NR
12301	Tairua	Broken Hills	T12:537518	EW	750703		NR
12402	Tairua	Wharf	T11:640618	EW	760316	830728	NR

12403	Tairua	Duck Point	T12:619569	EW	760316	830120	NR
12509	Wharekawa	Adams Farm Br	T12:623468	EW	910610		NR
40703	Mangakowhai	Kaingapipi	R17:885075	NIWA-Ham	710126		N
40708	Mokau	Totoro Br	R17:759908	NIWA-Ham	790405		N
40810	Awakino	Gorge	R17:610853	NIWA-Ham	790405		N
41301	Marokopa	Falls	R16:726253	NIWA-Ham	790403		N
41302	Tawarau	Te Anga	R16:725237	NIWA-Ham	790409		N
41601	Oteke	Kinohaku	R16:686356	NIWA-Ham	710322	940126	N
43402	Waikato	Ngaruawahia C/W	S14:996924	EW	570518		NR
43411	Pokaiwhenua	Forest Products Weir	T16:668278	NIWA-Ham	520101		N
43419	Waikato	Huntly Railway Br	S13:026023	EW	680609	800725	NR
43420	Waikato	Rangiriri	S13:989167	EW	650401		NR
43421	Waikato	Tuakau	R12:828321	EW	650309		NR
43424	Whangamarino	Control Structure Outlet	S12:929323	EW	700406		NR
43425	Whangamarino	Control Structure	S12:932322	EW	680118		NR
43431	Puniu	Pokuru Br	S15:115500	EW	850506		NR
43433	Waipa	Whatawhata	S14:997760	EW	690904		NR
43435	Waipapa	Ngaroma Rd	T16:425166	NIWA-Rot	640409		N
43440	Waipa	Pirongia	S15:037529	EW	6701		NR
43446	L Waikare	Telemetry	S13:084125	EW	810527		NR
43447	Waikato	The Elbow	R12:737338	EW	560601	860522	NR
43448	Waikato	Hoods Landing	R13:656292	EW	560601		NR
43459	Waikato	Port Waikato	R13:638229	EW	611219	770120	NR
43466	Waikato	Hamilton Tr Br	S14:118764	EW	751222		NR
43468	Waipa	Honikiwi	S16:030331	EW	810522		NR
43472	Waiotapu	Reporoa	U17:016022	NIWA-Rot	600224		N
43480	Mangaokewa	Te Kuiti Pumping Stn	S16:997162	EW	830303		NR
43481	Waipa	Otewa	S16:156234	EW	850522		NR

43486	Whangamarino	Ropeway	S12:952308	EW	801031		NR
43487	Whangamarino	Falls Rd	S13:039263	EW	640624		NR
43489	Matahuru	Waiterimu Rd	S13:083110	EW	840712		NR
43495	L Ohakuri	Mihi	U17:972967	NIWA-Rot	580901	830331	N
1009208	Waimakariri	Waimakariri Rd	T15:607508	EW	771209	870415	NR
1009209	Walmsley	Reservoir	T13:616234	EW	781102	841224	NR
1009213	Oraka	Pinedale	T15:562447	EW	790720		NR
1009216	Ohinemuri	Waihi	T13:620184	EW	800712	920326	NR
1009220	Waihou	Mill Rd Floodg Outl	T13:439211	EW	800721	870522	NR
1009230	Kuhatahi	Weir	T15:662505	EW	810722	920424	NR
1009235	Ohinemuri	Queens Head	T13:575171	EW	830819		NR
1009240	Waitekauri	Swingbridge	T13:565223	EW	841027		NR
1009242	Waihou	Sarjants	T13:416288	EW	850925		NR
1009245	Ohinemuri	Frendrups	T13:642197	EW	850327		NR
1009246	Rapurapu	Kinlochs Farm	T15:642637	EW	851223		NR
1043407	Mangatawhiri	SH2	S12:961407	EW	680423		NR
1043419	Pokaiwhenua	Puketurua	T15:490462	NIWA-Ham	630930		N
1043427	Mangakino	Dillon Rd	T17:489065	NIWA-Rot	640410		N
1043428	Tahunaatara	Ohakuri Rd	U16:787140	NIWA-Rot	640415		N
1043434	Mangakara	Hirsts	U17:988005	NIWA-Rot	640530	940124	N
1043446	Waikato	Mercer	S12:920336	EW	630614	870108	NR
1043468	Kuratau	SH41	T18:427546	EW	781114		NR
1043476	Otutira	Otutaru	T17:550822	NIWA-Rot	660810	800829	N
1043490	Otutira	Otutira	T18:560783	NIWA-Rot	660928	721011	N
1043493	Otutira	Otumoko	T18:563798	NIWA-Rot	651010	760114	N
1143402	Whangamarino	Slackline	S13:051264	EW	671207	920402	NR
1143406	Otutira	Otumaroke	T17:552814	NIWA-Rot	670803	800829	N
1143407	Purukohukohu	Weir	U17:923025	NIWA-Rot	670117	840502	N
1143408	Purukohukohu	Puruorakau	U17:912036	NIWA-Rot	681219	870119	N
1143409	Purukohukohu	Puruki	U17:912031	NIWA-Rot	681203		N

1143418	3 Mile Bay	SH1 Culvert	U18:779713	EW	761126	820924	NR
1143419	L Taupo	Kawakawa Bay	T18:562780	NIWA-Rot	670725	710714	N
1143427	Te Tahi	Puketotara	S15:991481	NIWA-Ham	710412		N
1143428	Ohote	Rotokauri	S14:027789	NIWA-Ham	681108	910813	N
1143437	Waikato	Orton	S13:917230	EW	810313	890619	NR
1143441	Otutira	Otukanuka	T17:554802	NIWA-Rot	680820	760114	N
1143442	Purukohukohu	Purutaka	U17:911035	NIWA-Rot	681219		N
1143444	Waikato	Reids Farm	U18:783777	NIWA-Rot	690923		N
1143450	Awaroa	Sansons Br Rotowaro	S14:948997	EW	851129		NR
1243414	Mangatangi	SH2	S12:041371	EW	860519		NR
1243435	Hinemaiaia	SH1 Br	U18:722566	EW	760210	810428	NR
1443423	Purukohukohu	Puruki-Rua	U17:908031	NIWA-Rot	710222		N
1443424	Purukohukohu	Puruki-Toru	U17:908030	NIWA-Rot	710205		N
1443433	Puruwai	Gorge	U17:921039	NIWA-Rot	720519		N
1443462	Mangahanene	SH1	T15:378592	NIWA-Ham	720926		N
1443463	Purukohukohu	Puruki-Tahi	U17:912031	NIWA-Rot	721212		N
1443467	Waikato	Huntly North	S13:011065	EW	740509	830114	NR
1443498	Mangawara	McConnells Br	S13:095017	EW	770915		NR
1443499	Mangawara	Jefferis	S13:200060	EW	740524		NR
1543403	Ten Foot Drain	Aka Aka	R12:674306	EW	710404	810116	NR
1543412	Hinemaiaia	Manungatera	U18:796509	EW	810429	870413	NR
1543413	Tauranga-Taupo	Te Kono	T19:636473	EW	760211		NR
1543420	Waimarino	Kepa Rd	T19:611425	EW	760924		NR
1543424	Waihaha	SH32	T18:434747	EW	760526		NR
1543447	Waikato	Ohaki	U17:987919	NIWA-Rot	760826		N
1543478	L Taupo	Acacia Bay	U18:734730	NIWA-Rot	781208		N
1543487	Te Waro	Puruhou	U17:911024	NIWA-Rot	791220	870119	N
1543495	Waikato	Huntly Power Stn	S13:005043	EW	830211		NR
1543497	Mangaonua	Dreadnought	S14:154748	EW	801119		NR
1643449	Mangakotukutuku	Ruku Blk D/S	S14:094720	EW	76	850404	NR

1643450	Mangaonua	Flume Rd	S14:298716	EW	830526	880903	NR
1643451	L Ohinewai	Tahuna Rd	S13:023098	EW	831124	890817	NR
1643456	Whakapipi	Harrisville Rd	R12:831366	EW	840306		NR
1643457	Whakapipi	SH22-Tuakau	R12:811365	EW	840305		NR
1643460	Clarkes Rd Stm	Clarkes Rd	S13:901288	EW	840822		NR
1643461	Kaniwhaniwha	Limeworks Rd	S15:939649	EW	840612		NR
1643462	Mangaokewa	Te Kuiti Pumping Stn	S16:997162	EW	830303		NR
1643463	Parker Lane	Parker Lane	R12:796374	EW	850411	930922	NR
1643464	Tararoa	Churchill Rd-Pukekawa	R13:890234	EW	850411	920227	NR
1843412	Pokeno	McDonalds Rd	R12:894373	EW	850328		NR
1843461	Pokaiwhenua	Wiltsdown Rd	T16:577350	EW	880516	930406	NR
1943481	Waitomo	Ruakuri Caves Br	S16:921244	EW	840925		NR
2043418	Purukohukohu	Purutakaiti	U17:911035	NIWA-Rot	851219		N
2043441	Waipapa	Mulberry Rd	T17:677019	NIWA-Rot	86		N
2043446	Mokauteure	Forest Rd	T17:668935	NIWA-Rot	86	910731	N
2043454	L Waahi	Huntly	S13:990024	EW	851217		NR
2043455	Mangakotukutuku	Mahons Mine	S14:946954	EW	860426		NR
2043469	Awaroa	Otaua Rd (Waiuku)	R12:638356	EW	860717		NR
2043493	Waiotapu	Campbell Rd	U17:024082	EW	861210		NR
2043497	Orakonui	Ngatamariki	U17:870934	EW	861209	920303	NR
2143401	Otamakokore	Hossock Rd	U16:955166	EW	861209		NR
2143404	Mangate	Te Weta Rd	U17:898092	EW	861210		NR
2143412	Otumaheke	Spa Hotel	U18:789768	EW	861210		NR
2743464	Hinemaiaia	Maungatera	U18:796509	EW	870413		R
3043407	Naike	Kaawa School Rd	R13:787058	NIWA-Ham	900508		N

BAY OF PLENTY

13306	Tuapiro	Farm Ford	T13:648069	EBOP	840202		R
13901	Mangawhai	Omokoroa	U14:767877	NIWA-Rot	710323		N
14201	Moturiki	Mt Maunganui	U14:913917	NIWA-Rot	710527		N

14601	Kaituna	L Rotoiti Outlet	U15:038484	NIWA-Rot	EBOP	60101	NR
14603	Waiteti	Tauranga Direct Rd	U15:915429	EBOP	760223	810204	NR
14604	Awahou	Tauranga Direct Rd	U15:922453	EBOP	750501		NR
14606	Waingaehe	SH30 Br	U16:003369	EBOP	751103		NR
14607	Waiohewa	SH30 Br	U15:018416	EBOP	750417		NR
14610	Utuhina	SH5 Br	U16:942364	EBOP	670929		NR
14615	L Rotorua	Wharf	U16:953364	NIWA-Rot	340206	770727	N
14624	L Rotorua	Mission Bay	U15:016455	NIWA-Rot	EBOP	520831	N
14628	Mangorewa	Saunders Farm	U15:047632	EBOP	670712		NR
15302	Tarawera	Awakaponga	V15:412557	EBOP	480527		NR
15308	L Rerewhakaaitu	Awaatua Bay	V16:154182	EBOP	521025	830325	N
15341	Tarawera	Lake Outlet Recorder	V16:174303	NIWA-Rot	711101		N
15401	Rangitaiki	Thornton	W15:507577	EBOP	65		R
15408	Rangitaiki	Murupara	V17:329984	NIWA-Rot	520917		N
15410	Whirinaki	Galatea	V17:370960	NIWA-Rot	521203		N
15412	Rangitaiki	Te Teko	V15:436444	NIWA-Rot	EBOP	520908	NR
15415	Pokairoa	Railway Culvert	V16:375146	NIWA-Rot	930930		N
15432	Rangitaiki	Kopuriki	V16:413140	NIWA-Rot	660717	800522	N
15453	Waihua	Gorge	V16:457208	NIWA-Rot	791220		N
15462	Wheao	Powerhouse	V18:216795	NIWA-Rot	851106		N
15464	Matahina	Western Weir	V16:447362	NIWA-Rot	870304		N
15466	Rangitaiki	Aniwhenua	V16:418163	NIWA-Rot	881221		N
15469	Pokairoa	Whiteley Rd	V16:349152	NIWA-Rot	930930		N
15471	Poumako	Riverway Rd	V16:357146	NIWA-Rot	930930		N
15509	Whakatane	Whakatane Town Wharf	W15:622537	EBOP	64		R
15514	Whakatane	Whakatane	W15:609475	NIWA-Rot	520218		N
15534	Wairere	Wainui Rd	W15:620526	NIWA-Rot	670928	940126	N
15536	Waimana	Ogilvies Br	W16:704129	EBOP	680214		NR
15901	Waioeka	Gorge Cableway	W16:877220	NIWA-Rot	580317		N

15909	Waioeka	SH2 Br	W15:854455	EBOP	820826		R
16001	Otara	SH35 Br	W15:869464	EBOP	820826		R
16501	Motu	Houpoto	X15:181609	NIWA-Rot	570603		N
16502	Motu	Waitangirua	X16:147233	NIWA-Rot	600602		N
16503	Motu	Mangaotane	X16:211354	NIWA-Rot	610913	840110	N
16511	Takaputahi	Ngawhakatatara	X16:124338	NIWA-Rot	781007	840111	N
17101	Raukokore	SH35 Br	Y14:400804	NIWA-Rot	791212		N
17301	Tauranga	Maruhinemaka	Y14:415847	NIWA-Rot	680910	930105	N
17601	Wharekahika	Hicks Bay	Z14:766897	GDC	930520		R
17602	Mangatutu	SH35	Z14:745867	GDC	741120	810101	NR
17904	Taurangakautuku	Tangihanga	Z14:727718	GDC	750320	810217	NR
18304	Mata	Pouturu	Y16:596378	GDC	890209		R
18309	Waiapu	Rotokautuku Br	Z15:756541	GDC	750101		R
18901	Hikuwai	No4 Br	Z16:700198	GDC	880830		R
18902	Hikuwai	Willow Flat	Z17:708100	GDC	750101		R
18913	Mangaheia	Willowbank	Y17:634066	NIWA-Rot	881123		N
19602	Waimata	Goodwin's Rd	Y18:510725	GDC	780421		R
19603	Taruheru	Courtneys Br	Y18:402795	GDC	930511		R
19609	Waimata	Monowai	Y17:494865	GDC	840620		R
19612	Taruheru	Hansens Rd Br	Y18:424736	GDC	810119		R
19616	Waru	MacLaurin Rd	Y18:444760	NIWA-Rot	840525		N
19701	Waipaoa	Kanakanaia Br	Y17:354932	GDC	600101		R
19702	Waipaoa	Waipaoa Stn	Y16:339126	GDC	790117	870305	R
19703	Waipaoa	Bolitha Rd	Y18:375747	GDC	910828		R
19704	Waipaoa	Matawhero	Y18:379715	GDC	730101		R
19706	Waihora	No 3 Bridge	Y17:396973	GDC	861204		R
19708	Waikohu	Mahaki	X17:223977	GDC	791005		R
19709	Wharekopae	Killarney	X17:163851	GDC	781205	861231	R
19711	Waingaromia	Terrace	Y17:411043	GDC	790515		R
19712	Mangatu	Omapere	X17:288026	GDC	830830		R

19714	Waihuka	No 3 Bridge	X17:230936	GDC	861216		R
19719	Waipaoa	Kaiteratahi Br	Y17:374866	GDC	890406		R
19734	Waikohu	No 1 Br	X17:083997	NIWA-Rot	780712		N
19741	Wharekopae	Rangimoe Station	X17:160848	GDC	831206		R
19749	Te Arai	Reay's Br	X18:296634	GDC	781103	840917	R
19766	Te Arai	Pykes Weir	X18:286604	GDC	840101		R
19778	Gentle Annie	Weir	Y18:313716	NIWA-Rot	831010	930103	N
19779	McPhails Stm	Waingake Rd	X18:298643	NIWA-Rot	831125		N
19780	Pouarua	Weir	Y17:347813	NIWA-Rot	850710		N
1014641	Ngongotaha	SH5 Br	U15:900414	NIWA-Rot	750521		N
1014644	Waiowhiro	Bonnington's Farm	U16:935388	EBOP	751022		NR
1014645	Pomare	Diana Place	U16:922348	NIWA-Rot	760217	860729	N
1014646	Te Ngae Drain	Te Ngae Rd	U16:958345	NIWA-Rot	751107	860715	N
1114607	Kaituna	Clarke's	U14:053778	EBOP	800424		R
1114608	Kaituna	Hicksons	U14:084783	EBOP	800506		R
1114609	Kaituna	Taaheke	U15:035499	NIWA-Rot	811021		N

HAWKES BAY

20101	Kopuawhara	Railway Br	Y19:306319	HBRC	810429		NR
21302	Waiatai	Taits Br	X19:976335	HBRC	790510	850117	NR
21401	Wairoa	Marumaru	X19:962472	Niwa-Hav	800215		N
21409	Waiau	Otoi	W19:620427	Niwa-Hav	680801		N
21410	Waihi	Waihi	W18:699505	Niwa-Hav	680801		N
21412	L Waikaremoana	Onepoto	W18:682590	Niwa-Hav	790618		N
21415	Wairoa	Railway Br	X19:904353	HBRC	900622		NR
21420	Mokau	SH38	W18:663667	HBRC	900116		NR
21437	Hangaroa	Doneraille Park	X18:088642	HBRC	740531		NR
21458	Waikaretaheke	Kaitawa Weir	W18:689586	Niwa-Hav	880202		N
21493	Waiau	Ardkeen	W19:818417	HBRC	880312		NR
21499	Ruakituri	Sports Ground	X18:992556	HBRC	851003		NR

21601	Tahekenui	Glenstrae	W19:782310	Niwa-Hav	690101		N
21801	Mohaka	Raupunga	W19:672285	Niwa-Hav	580801		N
21803	Mohaka	Glenfalls	V20:240188	Niwa-Hav	590801		N
22502	Sandy Ck	SH2	V20:463156	HBRC	760326	870309	NR
22503	Mahiaruhe	Tutira Outlet SH2	V20:450144	HBRC	771007	870112	NR
22802	Esk	Waipunga Br	V20:391951	HBRC	631111		NR
22809	Esk	Berry Rd	V20:377128	HBRC	920623		NR
22832	Otakowai	Dam Site	V20:374040	HBRC	780612	860910	NR
22901	Wharerangi	Codds	V21:382843	HBRC	761210	880711	NR
22903	Ahuriri Lagoon	Causeway	V21:419841	HBRC	770811	860609	NR
23001	Tutaekuri	Puketapu	V21:357812	HBRC	681217		NR
23005	Ngahere	Ngahere Weir	U20:043070	Niwa-Hav	680221		N
23007	Ngahere	Sub-basin	U20:048068	Niwa-Hav	740712	801015	N
23019	Mangaone	Rissington	V21:300903	HBRC	900608		NR
23032	Tutaekuri	Puketapu (F/W site)	V21:357812	HBRC	780413		NR
23047	Tutaekuri	Ngaroto Rd	V21:219888	HBRC	910418		NR
23102	Ngaruroro	Fernhill	V21:330729	HBRC	520813		NR
23103	Ngaruroro	Whana Whana	U21:019777	HBRC	600901		NR
23104	Ngaruroro	Kuripapango	U20:969974	Niwa-Hav	630909		N
23105	Poukawa	Douglas Rd	V22:298533	HBRC	741014		NR
23106	Taruarau	Taihape Rd	U20:873914	Niwa-Hav	631204		N
23110	Ngaruroro	Ohiti	V21:271701	HBRC	710413		NR
23138	Karamu	Floodgates	V21:427708	HBRC	720828		NR
23149	L Poukawa	Te Hauke	V22:270523	HBRC	760918		NR
23150	Ngaruroro	Chesterhope Br	V21:425715	Niwa-Hav	761125		N
23169	Irongate	Clarks Weir	V21:367666	HBRC	780310		NR
23184	Raupare	Ormond Rd	V21:398713	HBRC	820129		NR
23201	Tukituki	Red Br	V22:466581	NIWA-Hav	680512		N
23203	Tuki Tuki	Waipukurau (SH2)	V23:138291	HBRC	880616		NR

23207	Tuki Tuki	Tapairu Rd	V22:183312	HBRC	870617		NR
23209	Otane	Glendon	V22:167406	NIWA-Hav	640424		N
23210	Omakere	Fordale	V23:276250	NIWA-Hav	630913		N
23211	Waipawa	Waipawa(SH2)	V22:163337	HBRC	610807	891201	NR
23214	Tukituki	Ashcott SH50 Br	U22:965356	HBRC	790919		NR
23218	Makaroro	Burnt Br	U22:928488	HBRC	750702		NR
23219	Waipawa	Fletchers Crossing	U22:928479	NIWA-Hav	740731	851106	N
23220	Tukipo	SH50(Punawai)	U22:948324	HBRC	761216		NR
23221	Mangatewai	SH50	U23:943300	HBRC	760504	811103	NR
23223	Maharakeke	Station Rd	U23:041255	HBRC	770301	831118	NR
23235	Waipawa	RDS	V22:153339	HBRC	880422		NR
23236	Makaretu	Watson’s Reach	U23:924270	HBRC	761222	821101	NR
23246	Makara	Brooklands	V22:382352	HBRC	761110	921110	NR
23252	Tukituki	Folgers Lake	U22:867433	HBRC	790412		NR
23302	Maraetotara	Waimarama Rd	V22:487561	HBRC	911017		R
23701	Pouhokio	Allens Br	V22:498441	NIWA-Hav	640518	711031	N
24325	Porangahau	Wallingford	V23:156048	HBRC	800819		NR
1021404	Aniwaniwa	L Waikaremoana (SH38)	W18:725654	HBRC	881215		NR
1021407	Hopuruahine	At the Caskades	W18:634702	HBRC	891213		R
1021445	Waikaretaheke	Terapatiki Br	W18:738523	HBRC	940223		NR
1023149	TutaekuriWaimat e	Goods	V21:384751	HBRC	780801		NR
1023150	Karewarewa	Turamoe Rd	V21:341622	HBRC	781115	900430	NR
1023160	Mangarau	Drop Structure	V21:430626	HBRC	791106		NR
1023181	Southland Drain	Norton Rd	V21:398645	HBRC	850719		NR
1023262	Ngahape	Arlington Rd	U23:080228	HBRC	851217	910413	NR
1123148	Awanui	Flume	V21:357613	HBRC	830928		NR
1123149	Maraekakaho	D/Stm Taits Rd	V21:170668	HBRC	830630	930106	NR
1123150	Poporangi	Ohara Station	U21:057747	HBRC	840316		NR
1123153	Poukawa	U/S Control Gate	V22:301530	HBRC	900810		NR

1123156	Longlands	Longlands Drain	V21:369637	HBRC	931026		NR
1123247	Papanui	Newmans Ford	V22:255414	HBRC	781211	910604	NR
1123266	Mangatarata	Farm Rd	V23:148249	HBRC	830608	900106	NR
1223206	Kiorerau	L Hatuma Control	V23:109247	HBRC	800312	930512	NR
1223216	Tuki Tuki	Shag Rock	V22:265331	HBRC	880113		NR

TARANAKI

34307	Patea	Mangamingi	Q20:375977	TRC	750417	840502	NR
34308	Patea	Skinner Rd	Q20:261064	TRC	780227		NR
34309	Mangaehu	Bridge	Q20:360009	TRC	780111		NR
34802	Tawhiti	Duffys Farm	Q21:243774	TRC	850510		N
35004	Waingongoro	Eltham Rd	Q20:206965	TRC	741219		NR
35005	Waingongoro	SH45	Q21:140803	TRC	801127		NR
35006	Mangatoki	Hastings Rd	Q20:158946	TRC	830504		NR
35201	Kapuni	SH45	P21:084831	TRC	800618		NR
35506	Kaupokonui	Glenn Rd	P21:029842	TRC	780404		NR
37101	Okahu	Ngariki Rd	P20:891073	NIWA-Wng, TRC	801216	860104	NR
38002	Stony	Mangatete Rd	P20:876196	NIWA-Wng, TRC	790928	860109	NR
38904	Huatoki	Mill Rd	P19:027373	TRC	810729	901102	NR
39401	Waiongona	Waitara Intake	Q19:143346	NIWA-Wng, TRC	750122	800325	NR
39402	Mangaoraka	Corbett Rd	Q19:126381	TRC	750416		NR
39403	Waiongona	SH3A	Q19:144338	TRC	800410		NR
39404	Waiongona	Devon	Q19:141422	TRC	841220		NR
39503	Waitara	Bertrand Rd	Q19:187389	TRC	800207		NR
39509	Ngatoro	Bedford Rd	Q19:123230	NIWA-Wng, TRC	750416	801103	NR
39510	Ngatoro	SH3	Q19:151250	TRC	750618		NR
39511	Maketawa	SH3	Q19:161225	TRC	801013		NR
39594	Waitara	Mangaoapa Rd	Q19:408223	TRC	910516		NR
39595	Manganui	Everett Park	Q19:218326	TRC	910613		NR

MANAWATU-WANGANUI

25003	Akitio	Weber	U24:919832	MWRC	791102		NR
31902	L Waitawa	Youth Camp	S25:936512	MWRC	750320	800714	R
32001	Manakau	Gleesons Rd	S25:968516	MWRC	781123	910517	R
32107	Ohau (Water race)	D/S Culvert	S25:073578	MWRC, NIWA-Wel	910208		NR
32503	Manawatu	Weber Rd	U23:751027	MWRC	540402		R
32504	Manawatu	Hopelands	T24:616899	MWRC	890704		R
32507	Manawatu	Poplar Rd	S24:169826	MWRC	791218	860104	R
32514	Oroua	Almadale	T23:364113	MWRC	54		R
32526	Mangahao	Ballance	T24:468818	MWRC	540307		NR
32527	Tiraumea	Kaitawa	T24:539753	MWRC	471205	811231	R
32529	Tiraumea	Ngaturi	T24:578780	MWRC	570529		NR
32531	Mangatainoka	Suspension Br	T24:521824	MWRC	531118		NR
32547	Manawatu	Moutoa	S24:110766	MWRC	631212		R
32548	Manawatu	Moutoa Floodway	S24:108759	MWRC	63		R
32553	Mangahao	Kakariki	T25:317685	MWRC	641012		R
32557	Mangaone	Milson Line	T24:311953	MWRC	700920		NR
32563	Oroua	Kawa Wool	S23:287038	MWRC	670518	920722	NR
32573	Coal Ck	Pohangina West Rd	T23:531172	MWRC	701104	770824	R
32576	Pohangina	Mais Reach	T23:468053	MWRC	690610		NR
32580	Manawatu	Ruahine St	T24:345908	MWRC	711216	870211	NR
32590	Koputaroa	Tavistock Rd	S25:078651	MWRC	740111		NR
32592	Manawatu	Foxton	S24:994793	MWRC	740807		R
32599	Kumeti	SH2(Napier)	T23:689029	MWRC	750626	800821	NR
32602	Puke Puke	Lake Outlet	S24:008945	NIWA-Wng	710624	800701	N
32701	Rangitikei	Kakariki	S23:183172	MWRC	721123	940324	R
32702	Rangitikei	Mangaweka	T22:504513	NIWA-Wng	531230		N
32705	Rangitikei	Otara	T22:436449	NIWA-Wng	630504	710524	N
32708	Rangitikei	Springvale	U21:714874	NIWA-Wng	630927	740502	N

32715	Porewa	Tututotara	S23:212280	NIWA-Wng	630325	910730	N
32723	Maungaraupi	Maungaraupi	S23:212281	MWRC	700304	760429	R
32726	Hautapu	Taihape	T21:506668	NIWA-Wng	630502		N
32732	Moawhango	Waiouru	T20:468948	NIWA-Tur	580224	800610	N
32733	Moawhango	Moawhango	T21:557745	NIWA-Wng	630928		N
32734	Mangaio	Waiouru	T20:456057	NIWA-Wng	671025	760107	N
32735	Rangitawa	Halcombe	S23:193166	NIWA-Wng	690325	801007	N
32739	Tutaenui	Hammond St	S23:132237	MWRC	680328		R
32754	Makohine	Viaduct	T22:395450	NIWA-Wng	770320		N
32755	Kawhatau	Parenga	T22:518547	MWRC	770310	861118	NR
32757	Moawhango	Lake Gauge	T20:472962	NIWA-Tur	790423		N
32758	Moawhango	Moawhango Tunnel	T20:499177	NIWA-Tur	791008		N
32760	Rangitikei	McKelvies	S24:033985	MWRC	801203	861117	R
33003	Turakina	SH3 Br	S23:985279	NIWA-Wng	770201		N
33004	Turakina	Otairi	S22:236471	NIWA-Wng	710602		N
33101	Whangaehu	Kauangaroa	S22:045397	NIWA-Wng	MWRC	710618	NR
33107	Whangaehu	Karioi	S21:218864	NIWA-Wng	621101		N
33111	Mangawhero	Ore Ore	S21:045794	NIWA-Wng	620507		N
33112	Tokiahuru	Whangaehu Junction	S21:217871	NIWA-Wng	790813	940112	N
33114	Waitangi	Tangiwai	T21:316886	NIWA-Wng	671122	940112	N
33115	Mangaetoroa	School	S20:017932	NIWA-Wng	MWRC	681230	NR
33116	Wahianoa	Karioi	T20:377982	NIWA-Wng	670415	720913	N
33117	Makotuku	SH49A Br	S20:103011	NIWA-Wng	680207		N
33118	Mangawhero	Burns St	S20:148971	MWRC	750218	820211	R
33130	Whangaehu	Mangaio Tunnel	T20:445990	NIWA-Tur	790710		N
33301	Whanganui	Paetawa	S22:937566	NIWA-Wng	570726		N
33302	Whanganui	Te Maire	S19:998490	NIWA-Tur	510418		N
33307	Whanganui	Headwaters	T19:347410	NIWA-Tur	591202	781101	N
33309	Manganui-o-te-ao	Ashworth	S20:003082	NIWA-Wng	610816	800807	N

33311	Tangarakau	Tangarakau	R19:712414	NIWA-Tur	611007	690109	N
33312	Retaruke	Kawautahi	S19:022347	NIWA-Tur	610705	690103	N
33313	Ohura	Tokorima	R18:863521	NIWA-Tur	610907	780907	N
33316	Ongarue	Taringamutu	S18:043578	NIWA-Tur	620805		N
33320	Whakapapa	Footbridge	S19:226293	NIWA-Tur	580224		N
33324	Mangatepopo	Ketetahi	T19:321347	NIWA-Tur	580224	680626	N
33338	Whanganui	Matapuna	S18:101554	NIWA-Tur	640703	730501	N
33341	Mangaroa	Ohura Town Br	R18:821608	NIWA-Tur	650507	710318	N
33345	Whanganui	Pipiriki	R21:859897	MWRC	601118	861231	NR
33347	Whanganui	Te Porere	T19:344368	NIWA-Tur	660113		N
33348	Whanganui	Wades Landing	R19:886306	NIWA-Tur	660128	730104	N
33356	Whanganui	Piriaka	S18:134531	NIWA-Tur	701202		N
33358	Whakapapa	Owhango	S19:178426	MWRC	841128	911004	R
33359	Whanganui	Wairehu Canal	T19:401398	NIWA-Tur	710201		N
33365	Whanganui	Town Br	R22:857391	NIWA-Wng	WGC	720913	N
33366	Matarawa	Diversion	R22:893411	MWRC	770513		R
33367	Manganui-o-te-Ao	Orautoha Dam Site	S20:064091	MWRC	790226	840821	N
33380	Whanganui	Te Whaiau Culvert	T19:357390	NIWA-Tur	910321		N
33502	Kai Iwi	Handley Rd	R22:726455	NIWA-Wng	780405		N
34202	Whenuakura	Nicholson Rd	Q21:428602	NIWA-Wng	830302		N
34305	Patea	McColls Br	Q21:429757	NIWA-Wng	861112		N
36001	Punehu	Pihama	P21:886899	NIWA-Wng	700101		N
36003	Mangatawa	McKays	P21:887899	NIWA-Wng	851210		N
37503	Kapoaiaia	Lighthouse	P20:755143	NIWA-Wng	860217		N
38401	Timaru	SH45	P19:896274	NIWA-Wng	800324	940105	N
38501	Oakura	Surrey Hill Rd	P19:936311	NIWA-Wng	791128	870114	N
38905	Mangaotuku	Rainsford St	P19:007374	NIWA-Wng	811029	870112	N
39201	Waiwakaiho	SH3	P19:082292	NIWA-Wng	800130		N
39501	Waitara	Tarata	Q19:278271	NIWA-Wng	681218		N

39504	Manganui	Tariki Rd	Q19:202201	NIWA-Wng	620201	740111	N
39506	Motukawa	Tail Race	Q19:293236	NIWA-Wng	720531	940106	N
39508	Manganui	SH3	Q20:189130	NIWA-Wng	720531		N
1032501	Kumeti	Te Rehunga	T23:663052	MWRC	760902		NR
1032503	Tamaki	SH2(Napier)	U23:711040	MWRC	750604	831231	R
1032504	Tamaki	Water Supply Weir	U23:709111	MWRC	760109		R
1032514	Manawatu	Diagonal Drain	S24:043728	MWRC	771006	840127	R
1032516	Kiwitea	Spur Rd Extension	T23:325100	MWRC	761005		NR
1032517	Tokomaru	Quarry	S24:240766	MWRC	791213		R
1032518	Makakahi	Hamua	T25:424676	MWRC	791219		NR
1032555	Mangatainoka	Larsens Br	T25:308596	MWRC	830720		R
1032560	Manawatu	Teachers College	T24:331892	MWRC	870211		NR
1032561	Makino	Rata St	S23:275051	MWRC	861223		R
1032562	Makino	Reids Line	S23:297090	MWRC	870130		R
1032564	Makino	Boness Rd	S23:254023	MWRC	911209		R
1043459	Tongariro	Turangi	T19:537417	NIWA-Tur	480801		N
1043460	Tongariro	Puketarata	T19:550331	NIWA-Tur	580224		N
1043461	Tongariro	Upper Dam	T20:493166	NIWA-Tur	580224		N
1043464	Poutu	Footbridge	T19:495329	NIWA-Tur	590227	711110	N
1043466	Waihohonu	Desert Rd	T20:463173	NIWA-Tur	610802		N
1043478	Rotoaira	Lake Gauge	T19:449329	NIWA-Tur	530910		N
1143420	L Taupo	Tokaanu	T19:494465	NIWA-Tur	670608		N
1232564	Manga-Atua	Hopelands Rd	T24:580930	MWRC	791218	900123	R
1232566	Manawatu	Upper Gorge	T24:494930	MWRC	790716		R
1443434	Poutu	Dam Outlet	T19:499326	NIWA-Tur	711110	850701	N
1443464	Tongariro	Poutu Tunnel	T19:541267	NIWA-Tur	731205		N
1443495	Tongariro	Rangipo Barrage	T20:499178	NIWA-Tur	681004		N
1643444	Poutu	Ford	T19:497328	NIWA-Tur	830526		N
1643445	Tongariro	D/S Poutu Intake	T19:541269	NIWA-Tur	821028		N
2043474	Waihohonu	Dam	T20:492184	NIWA-Tur	860915		N
2043475	Waihohonu	Tunnel	T20:492184	NIWA-Tur	860929		N

WELLINGTON

25902	Whareama	Waiteko	T26:660231	NIWA-Wel	700409		N
26502	Kaiwhata	Stansborough	T27:546978	NIWA-Wel	880101		N
27303	Pahao	Hinakura	T27:317865	NIWA-Wel	WERC	860904	NR
29201	Ruamahanga	Wardells	T26:347192	WERC	541110		NR
29202	Ruamahanga	Waihenga	S27:146984	WERC	NIWA-Wel	561231	NR
29203	Ruamahanga	Tuhitarata	S27:000887	WERC	560331	741217	NR
29209	L Wairarapa	Burlings	S27:920952	WERC	530918		NR
29222	Huangaroa	Hautotara	S27:173871	WERC	610101	840109	NR
29224	Waiohine	Gorge(new site)	S26:117183	WERC	541227		NR
29231	Taueru	Te Weraiti	T26:421201	WERC	691210		NR
29237	L Onoke	Ferry	R28:892770	WERC	530131		NR
29238	L Wairarapa	Barrage North	S27:934856	WERC	740101		NR
29239	Ruamananga	Barrage South	S27:934858	WERC	740101		NR
29242	Atiwhakatu	Mt Holdsworth Rd	S26:226315	WERC	661226		NR
29244	Whangaehu	Waihi	T26:441380	NIWA-Wel	670510		N
29246	Waingawa	Upper Kaituna	S26:227324	WERC	760514		NR
29250	Ruakokopatuna	Iraia	S28:085778	NIWA-Wel	690529		N
29251	Tauherenikau	Gorge	S26:080129	WERC	760322		NR
29254	Ruamahanga	SH2	S25:299461	WERC	741212		NR
29259	Pakaraka	Te Whiti	T26:366197	NIWA-Wel	780706	921110	N
29501	Orongorongo	Dam	R27:809879	WERC	760415	850522	NR
29502	Big Huia	Dam	R27:807882	WERC	760415	841114	NR
29503	Orongorongo	Upper Dam Site	R27:825927	WERC	790201		NR
29605	Wainuiomata	Leonard Wood Park	R27:731896	WERC	770414		NR
29606	Wainuiomata	Manuka Track	R27:786924	WERC	820610		NR
29803	Hutt	Silverstream	R27:776050	WERC	620908	800114	NR
29808	Hutt	Kaitoke	S26:942150	NIWA-Wel	671221		N
29809	Hutt	Taita Gorge	R27:764034	WERC	790316		NR
29811	Hutt	Boulcott	R27:712992	WERC	640922		NR
29816	Hutt	Taita Rock	R27:748026	WERC	740808	791030	NR

29818	Hutt	Birchville	R27:856099	NIWA-Wel	700907		N
29830	Mangaroa	Te Marua	R26:887102	WERC	691010		NR
29838	Hutt	Estuary Br	R27:693953	WERC	760928		NR
29841	Whakatiki	Dude Ranch	R26:806119	WERC	760908		NR
29843	Pakuratahi	Truss Br	S27:937069	WERC	780522		NR
29844	Akatarawa	Cemetery	R26:863112	WERC	790219		NR
29845	Waiwhetu	Whites Line East	R27:710963	WERC	69		NR
29851	Lake One	Te Marua	S26:906114	WERC	850611		NR
29852	Lake Two	Te Marua	S26:903113	WERC	850225		NR
29853	Hutt	Te Marua	S26:902121	WERC	84		NR
29901	Korokoro	Mill Weir	R27:660972	WERC	801209		NR
30501	Makara	No 1	R27:520944	NIWA-Wel	561106	760101	N
30502	Makara	No 2	R27:520940	NIWA-Wel	561105	760102	N
30503	Makara	No 3	R27:521936	NIWA-Wel	561106	760101	N
30504	Makara	No 4	R27:520939	NIWA-Wel	561105	760101	N
30507	Makara	No 7	R27:522934	NIWA-Wel	561106	760101	N
30508	Makara	No 8	R27:522934	NIWA-Wel	570601	760101	N
30510	Makara	No 10	R27:520958	NIWA-Wel	600228	760430	N
30511	Makara	No 11	R27:521959	NIWA-Wel	601030	760430	N
30516	Mill Ck	Papanui	R27:589017	NIWA-Wel	690424		N
30701	Porirua	Town Centre	R27:646056	WERC	650908		NR
30802	Pauatahanui	Gorge	R27:715082	NIWA-Wel	750530		N
31101	Taupo	Flax Swamp	R26:673128	WERC	790817		NR
31401	Wharemauku	Coastlands	R26:789302	WERC	800430	860124	NR
31504	Waikanae	Water Treatment	R26:846331	WERC	750302		NR
31720	Mangaone	Ratanui	S26:919399	WERC	930113		NR
31801	Otaki	Gorge	S25:957401	WERC	580120	821124	R
31803	Otaki	Tuapaka	S25:952410	NIWA-Wel	720531	820525	N
31807	Otaki	Pukehinau	S25:955402	NIWA-Wel	800717		N
32105	Ohau	Water Race	S25:077579	NIWA-Wel	740110	790816	N
32106	Ohau	Rongomatane	S25:072577	NIWA-Wel	780710		N
1438001	Wellington Harbour	Waterloo Wharf	R27:591901	WERC	900813		NR

NELSON-MARLBOROUGH

52003	Aorere	Devils Boots	M25:785511	NIWA-Nel	TDC	760401	NR
52901	Takaka	Kotinga Br	N26:939373	TDC	701008		NR
52902	Takaka	Harwoods	N26:930195	NIWA-Nel	750325		N
52903	Anatoki	Happy Sams	M26:889356	TDC	790905		NR
52904	Waingaro	Hanging Rock	M26:889296	TDC	790905		NR
52905	Takaka	Pages Cut	N25:927406	TDC	811209	900308	NR
52906	Waikoropupu	Bubbling Spring	N25:908405	TDC	850131		NR
52907	Waikoropupu Spr	Springs River	N26:907399	TDC	741224		NR
52908	Waikoropupu	Egdirb	N25:912405	TDC	811127	870907	NR
52910	Fish Creek	Waikoropupu Springs	N26:905397	TDC	850404		NR
52916	Cobb	Trilobite	M27:773088	NIWA-Nel	690501		N
56901	Riwaka Sth Br	Moss Bush	N26:034172	TDC	611201		NR
56902	Riwaka	Littles	N26:023189	TDC	810501		NR
56904	Riwaka	Hickmotts	N26:091155	TDC	940126		NR
57003	Motueka	Blue Gum Corner	N26:075114	TDC	631223	750420	NR
57004	Baton	Baton Flats	M27:868874	TDC	710920		NR
57005	Wangapeka	Swiming Hole	M28:828776	TDC	660306	720801	NR
57006	Wangapeka	Swingbridge	M28:812765	TDC	720803	870322	NR
57008	Motueka	Gorge	N28:028526	TDC	650101		NR
57009	Motueka	Woodstock	N27:951943	NIWA-Nel,TDC	690211		NR
57014	Stanley Brook	Barkers	N27:949877	NIWA-Nel	691215		N
57016	Long Gully	Meads Rd	N28:970619	NIWA-Nel	730807	830317	N
57020	Roughns	Weir	N28:980555	NIWA-Nel	760706	860701	N
57021	Graham Ck	Weir	N29:959497	NIWA-Nel	770330	860701	N
57022	Hunters	Weir	N29:988479	NIWA-Nel	770428		N
57023	Kikiwa	Weir	N28:979502	NIWA-Nel	770620	860701	N
57024	Tadmor	Mudstone	M28:876728	TDC	770601		NR
57025	Wangapeka	Walter Peak	N27:902851	TDC	810321		NR
57035	Hope	Tadmor Saddle	M28:807584	TDC	881102		NR
57036	Motupiko	Christies Br	M27:778818	TDC	900119		NR

57101	Moutere	Old House Rd	N27:102970	TDC	610630	860120	NR
57102	NZ CO Ditch	Riverside Community	N27:094047	TDC	711104	880204	NR
57300	Waimea Inlet	Mapua Wharf	N27:184944	TDC	860508		NR
57402	Moutere	Catchment 2	N27:169837	NIWA-Nel	620111	880112	N
57403	Moutere	Catchment 3	N27:166833	NIWA-Nel	620501	860714	N
57404	Moutere	Catchment 4	N27:165831	NIWA-Nel	620428	860714	N
57405	Moutere	Catchment 5	N27:164831	NIWA-Nel	620428	880112	N
57406	Moutere	Catchment 6	N27:162832	NIWA-Nel	620112	880112	N
57413	Moutere	Catchment 13	N27:163839	NIWA-Nel	620428	860714	N
57414	Moutere	Catchment 14	N27:161842	NIWA-Nel	640424	880112	N
57415	Moutere	Catchment 15	N27:160843	NIWA-Nel	640101	880112	N
57500	Waimea Inlet	Shags Roost	N27:256899	TDC	770816		NR
57501	Wai-iti	Footbridge	N27:169808	TDC	701209	760902	NR
57502	Wairoa	Gorge	N28:211791	NIWA-Nel,TDC	571111	921203	NR
57503	Roding	Weir	O27:321834	TDC	470616	841128	NR
57504	Wai-iti	Brightwater	N27:185824	TDC	760607	860217	NR
57505	Sth Pigeon Trib	Bradleys Rd	N27:098812	NIWA-Nel	781215	860701	N
57506	Nth Pigeon Trib	Sharpes Rd	N27:116832	NIWA-Nel	790418	860701	N
57508	Moutere	Catchment 8	N27:171828	NIWA-Nel	620427	860714	N
57509	Moutere	Catchment 9	N27:170827	NIWA-Nel	760706	860714	N
57510	Moutere	Catchment 10	N27:167824	NIWA-Nel	620429	860714	N
57512	Moutere	Catchment 12	N27:162826	NIWA-Nel	620427	860714	N
57517	Wai-iti	Belgrove	N28:065726	TDC	831213		NR
57520	Wai-iti	Livingston Rd	N27:188830	TDC	860820		NR
57521	Wairoa	Irvines	N28:216782	NIWA-Nel,TDC	920331		NR
57802	Maitai	Smiths Ford	O27:390902	TDC	790327		NR
57804	Maitai	South Branch	O27:412888	TDC	810220		NR
58101	Wakapuaka	Hira	O27:431991	TDC	780808		NR
58301	Collins	Drop Structure	O27:547052	NIWA-Nel	6009		N
58902	Pelorus	Bryants	O27:573891	NIWA-Nel	771028		N

58903	Rai	Rai Falls	O27:580911	MDC	790530		NR
58904	Pelorus	Wakamarina	O27:685913	NIWA-Nel	890726		N
59003	Kaituna	Okaramio	P28:745778	NIWA-Nel	690924	770304	N
59201	Kenepuru	Kenepuru Head	P27:042042	NIWA-Nel	801216		N
60104	Taylor	Borough Weir	P28:879564	MDC	620401		NR
60107	Wairau	Bar	P28:983665	MDC	581003		R
60108	Wairau	Tuamarina	P28:906737	MDC	600705		NR
60110	Waihopai	Craiglochart	O28:673540	MDC	600707		NR
60112	Branch	Recorder	N29:252448	MDC	5809	850217	NR
60114	Wairau	Dip Flat	N29:035238	NIWA-Nel	510601		N
60115	Wye	Thompson Gorge	O29:361455	MDC	620724	86	NR
60116	Wairau	Hells Gate	N30:015064	NIWA-Nel	650227	760217	N
60118	Wairau	Dicks Rd	P28:912720	MDC	640713		R
60119	Wairau	Narrows	O28:679652	MDC	790619		R
60120	Branch	Weir Intake	N29:252452	MDC	83		NR
60121	Taylor	Dam	P28:877591	MDC	890522		R
60123	Omaka	Gorge	P28:724527	MDC	931222		R
60124	Taylor	Hutchson St	P28:898649	MDC	931126		R
60203	Awatere	Awapiri	P29:707300	MDC	761111		NR
93202	Buller	Longford	M29:590380	NIWA-Nel	631005		N
93209	Maruia	Falls	L29:478273	NIWA-Nel	631207		N
93211	Matakitaki	Mud Lake	M29:532287	NIWA-Nel	631121		N
93212	Mangles	Gorge	M29:624322	NIWA-Nel	580101		N
93213	Gowan	L Rotoroa	M29:763348	NIWA-Nel	340328		N
93214	Matiri	Lake Outlet	M29:545492	NIWA-Nel	790209	931125	N
93216	Buller	L Rotoiti	N29:952339	NIWA-Nel	510101	940112	N
93217	Glenroy	Blicks	M30:547053	NIWA-Nel	660402	800117	N

CANTERBURY

62103	Acheron	Clarence	N31:071703	NIWA-Chc	580402		N
62104	The Ribble	Airstrip	N31:069674	NIWA-Chc	711126	810127	N
62105	Clarence	Jollies	N31:023611	NIWA-Chc	580430		N
62106	Clarence	Glen Alton	P30:794999	CRC	790618	850627	NR
63101	Middle Creek	Beach Rd	O31:663708	CRC	801015		NR
63501	Rosy Morn	Weir	O31:555611	NIWA-Chc	780209		N
64301	Conway	Hundalee	O32:438449	NIWA-Chc	550905	670821	N
64601	Waiau	Leslie Hills	N32:927369	NIWA-Chc	611107	760311	N
64602	Waiau	Marble Point	N32:914408	CRC	671006		NR
64604	Waiau	Glen Hope	M32:737467	CRC	740131		R
64606	Waiau	Malings Pass	M31:811874	CRC	650121		NR
64608	Hope	Glynn Wye	M32:699465	CRC	740130		NR
64609	Waiau	Mouth	O33:396256	CRC	731130		NR
64610	Stanton	Cheddar Valley	N32:216418	NIWA-Chc	680101		N
64611	Waiau Main Race	Intake	N32:942342	NIWA-Chc	801113		N
65101	Hurunui	SH1 Br	N33:179121	CRC	741202		R
65103	Balmoral Irr Race	Intake	M33:747229	NIWA-Chc	850124		N
65104	Hurunui	Mandamus	M33:725240	NIWA-Chc	561026		N
65105	Hurunui	Jollie Brook	M33:557231	CRC	741113	921029	NR
65107	L Sumner	Outlet	M32:505314	CRC	560924		NR
65108	Hurunui	No 2 Hut Br	L32:373331	CRC	750507	920811	NR
65109	S Branch Hurunui	Esk Head	M33:550197	CRC	740918	921029	R
65901	Waipara	White Gorge	M34:789942	CRC	880225		R
66204	Ashley	Gorge	L34:473797	CRC	381108		R
66207	Stony Ck	Forbes Rd	M34:768748	NIWA-Chc	791220	860801	N
66208	Stony Creek Sth	Sawbench Rd	M34:756754	NIWA-Chc	790618	870220	N
66209	Stony Creek Nth	Stony Creek Rd	M34:757756	NIWA-Chc	790618	860801	N
66210	Ashley	Lees Valley	L34:431901	CRC	770210		R
66213	Okuku	Fox Ck	M34:603848	CRC	890202		R
66214	Ashley	Rangiora Traffic Br	M35:763694	CRC	910403		R

66401	Waimakariri	Old Highway Br	M35:818547	CRC	641130		NR
66402	Waimakariri	Gorge	L35:331605	CRC	2201		NR
66403	Waimakariri	Otarama	L34:244718	CRC	610930	750922	not
66404	Waimakariri	Esk	L34:257872	CRC	900919		R
66405	Camp Stream	Craigieburn	K34:044844	NIWA-Chc	671017		N
66417	Cust Main Drain	Threkelds Rd	M35:783606	CRC	801127		NR
66419	Bealey	Arthurs Pass	K33:924073	CRC	820329		NR
66424	Styx	Marshlands Rd	M35:823494	CCC	8612		R
66602	Avon	Gloucester St Br	M35:805419	CCC,CRC	800416		N
66603	Flemings Drain	Cashmere Weir	M36:802348	CRC	540518	760709	R
66620	Travis Swamp	Beach Rd	M35:856469	CRC	910220		R
67408	French Farm	French Farm Valley Rd	N36:024144	CRC	891130		R
67601	Reynolds	Brankins Br	N36:961130	NIWA-Chc	671221	760630	N
67602	HukaHuka	Lathams Br	N36:937175	NIWA-Chc	871214		N
67702	Kaituna	Kaituna Valley Rd	M36:844168	CRC	860609		NR
68001	Selwyn	Whitecliffs	L35:206487	NIWA-Chc,CRC	640526		NR
68002	Selwyn	Coes Ford	M36:632228	CRC	840229		NR
68003	Selwyn	Ridgens Rd	L36:371327	CRC	900531		R
68320	Doyleston Drain	Lake Rd	M36:579149	CRC	870211		NR
68501	Rakaia	SHBr	L36:320171	CRC	801212		NR
68502	Rakaia	Gorge	K35:015424	CRC	350726		NR
68503	Harper Diversion	L Coleridge	K34:847754	NIWA-Chc	710429		N
68504	L Heron	South Lake	J35:609446	CRC	380131	920520	NR
68509	Lake Stream	Rouses	J35:632500	CRC	750213	840510	NR
68515	Ramsay	L Ramsay	J35:410676	CRC	761216	820630	NR
68517	L Coleridge	Intake	K35:922618	NIWA-Chc	770503		N
68520	Lake Stream	Swingbridge	J35:605560	CRC	771109		NR
68521	Oakden Canal	Oakden Culvert	K34:832749	NIWA-Chc	771219		N
68523	Talus	Talus Tarn	J34:537726	NIWA-Chc	780504	860910	N
68526	Rakaia	Fighting Hill	K35:997437	NIWA-Chc	781219		N

68529	Dry Acheron	Water Race	K35:020558	NIWA-Chc	790409	910725	N
68534	Rakaia	Fishing Reserve	L37:490018	CRC	830304		NR
68602	Dry Creek	RDR Siphon	K36:005332	CRC	660617	870306	R
68801	Ashburton	SHBr	K37:086989	CRC	821223	881114	R
68806	Sth Ashburton	Mt Somers	K36:726261	CRC	670427		NR
68807	Sth Ashburton	Syphon	K36:820193	NIWA-Chc,CRC	830823		N
68808	Mill Ck	Bridge St	L37:111002	CRC	781017	890301	R
68810	Nth Ashburton	Old Weir	K36:876366	CRC	820224		NR
68816	Greenstreet	Recorder	K36:987140	CRC	851002		NR
68817	Woolshed Ck	Mt Somers	K36:763240	NIWA-Chc	940601		N
68818	Bowyers Stm	Staveley	K36:831298	NIWA-Chc	940617		N
69302	Rangitata	Klondyke	J36:666149	CRC	670901		NR
69303	Rangitata Div Rc	Montalto Drops	K36:765108	NIWA-Chc	730710	820430	N
69304	Mayfield/Hinds	Intake	K37:717065	NIWA-Chc	791011		N
69305	Valetta Main Race	Intake	K36:819178	NIWA-Chc	791018		N
69306	Ash/Lynhurst	Lateral 1	K36:947269	NIWA-Chc	791110		N
69307	Ash/Lynhurst	Intake	K36:977288	NIWA-Chc	791011		N
69324	Rangitata D.R.	Below Sandtrap	J36:696123	CRC	840611		NR
69505	Orari	Gorge	J37:653951	CRC	820908		NR
69506	Orari	Silverton	J37:649957	CRC	650201	830613	N
69601	Temuka	SHBr	K38:723600	CRC	821223	910909	R
69602	Temuka	Manse Br	K38:718612	CRC	910909		R
69614	Opuha	Skipton	J38:482790	CRC	360222		NR
69618	Opihi	Rockwood	J38:454690	CRC	630701		NR
69621	Rocky Gully	Rockburn	J38:325513	CRC	640115		NR
69625	Opawa	Mt Nessing Weir No 1	I38:278517	CRC	801007	860313	N
69626	Opawa	West Hills Weir No 2	I38:276521	CRC	801006	860313	N
69627	Exe	Kennaway Stn Weir 3	I38:237580	CRC	791212	870414	N
69628	Exe	Rowell’s Weir No 4	I38:240583	CRC	791212	860313	N

69629	Exe	Walsh's Weir No 5	I38:239592	CRC	790822	860313	N
69630	Exe	Shenley Weir No 6	I38:245613	CRC	790619	860313	N
69631	Kakahu	Christie's Weir No 7	J37:496816	CRC	810422	860313	N
69632	Kakahu	Stony Ck Weir No 8	J38:507798	CRC	810422	870415	N
69633	Kakahu	Mitchell's Weir No 9	J38:518795	CRC	801102	870415	N
69634	Kakahu	Turnbulls Weir No 10	J38:536777	CRC	801102	860313	N
69635	Tengawai	Picnic Grounds	J38:487546	CRC	820312		NR
69636	Levels I.S.	Parshall Flume	J38:632584	CRC	821230		N
69641	Opihi	Waipopo	K38:762586	CRC	821217		R
69643	Waihi	Waimarie	J37:628878	CRC	831027	900906	NR
69644	Te Moana	Glentohi	J37:583834	CRC	831220		NR
69645	Kakahu	Mulvihills	J38:538739	CRC	831206		NR
69649	Waihi	DOC Reserve	J37:617878	CRC	910412		R
70105	Pareora	Huts	J39:553423	CRC	820401		NR
70902	Waihao	McCulloughs Br	J40:497989	CRC	820924		NR
70905	Wainono Dead Arm	Poingdestres Rd	J40:639073	CRC	760915		R
70907	Waihao	Bradshaws Br	J40:642017	CRC	870608		R
71102	Otekaieke	Stockbridge	I41:141880	NIWA-Tek	701217	770218	N
71103	Hakataramea	Above MHBr	I40:112062	NIWA-Tek	631126		N
71104	Waitaki	Kurow	I40:080088	CRC	630529		NR
71106	Maerewhenua	Kellys Gully	I41:197820	NIWA-Tek	700304		N
71108	Waitaki	Parson's Rock	I40:904178	NIWA-Tek	630529	680721	N
71109	Otematata	Pumphouse	H40:878171	NIWA-Tek	640110	700110	N
71110	Waitaki	Below Dam	I40:064097	NIWA-Tek	921010		N
71116	Ahuriri	Sth Diadem	G39:497320	NIWA-Tek	630918		N
71117	Twizel	L Poaka	H38:784628	CRC	860702	950630	NR
71119	Ohau	SHBr	H38:777538	NIWA-Tek	630705	8007	N
71120	L Ohau	L Middleton	H38:588539	NIWA-Tek	630101	771205	N

71121	Twizel	SHBr	H38:794573	NIWA-Tek	620725	730403	N
71122	Maryburn	Mt MacDonald	I38:923783	NIWA-Tek	691022		N
71123	L Pukaki	Lake	H38:811656	NIWA-Tek	630920		N
71125	Hooker	Ball Hut Rd Br	H36:783146	NIWA-Tek	630902	790828	N
71127	Maryburn	Maryhill	I38:942715	CRC	631220	850813	NR
71128	Irishman	Windy Ridge	I38:978766	NIWA-Tek	640108	720118	N
71129	Forks	Balmoral	I37:014892	NIWA-Tek	620730		N
71131	Tekapo	Spillway	I37:079860	CRC	680606		NR
71132	L Tekapo	Lake	I37:074865	NIWA-Tek	630628		N
71134	Pukaki	Wardells	H38:828641	NIWA-Tek	640917		N
71135	Jollie	Mt Cook Stn	H37:835019	NIWA-Tek	641207		N
71136	Omarama	Wardells Br	H39:677305	CRC	880801	950630	NR
71148	Aviemore Spawning R	Below Dam	I40:003133	CRC	910611		R
71167	Otekaieke	Gorge	I41:141880	NIWA-Tek	760906	840903	N
71168	L Ohau	Moose Lodge	H38:648552	NIWA-Tek	770920		N
71169	Tekapo	Tekapo A	I37:065850	NIWA-Tek	780302		N
71170	Awamoko	Georgetown	J41:389868	NIWA-Tek	790309	950630	N
71171	L Ohau	Wetheralls	H38:562777	NIWA-Tek	911209		N
71173	Morven Glenavy	Crows Rd	J40:623994	CRC	800902		NR
71174	Morven Glenavy	Horsnells Rd	J40:613992	CRC	801106		NR
71175	Outlet Ck	L Alexandrina	I37:062936	CRC	810522		NR
71177	Waitaki	Mouth	J41:639846	NIWA-Tek	850328		N
71178	Otekaieke	Weir	I41:143880	NIWA-Tek	840709	950630	N
71184	Waikoura Channel	Irvine Rd	J41:456837	CRC	841106		R
71187	Redcliffs Irrigation	Intake	J40:369908	CRC	900920		R
71189	Omarama	Above Tara Hills	H39:625259	CRC	880209		R
71190	Morven Glenavy	Ross Rd	J41:503881	CRC	901102		R
71193	Lower Waitaki Irrig	Bortons	J41:362894	CRC	910723		R
3436871	Tutuiri	Schist Outcrop	N23:092275	NIWA-Chc	860727	940126	N
3446051	Te Awainanga	Falls	N23:229038	NIWA-Chc	860725		N
3446071	Awamata	Old Hydro Intake	N23:075019	NIWA-Chc	860724		N

OTAGO

71702	Kakanui	Clifton Falls	J41:326733	NIWA-Dun	690717	800605	N
71703	Kakanui	Clifton Falls Br	J41:327728	ORC	810409		R
71704	Kakanui	Naismith	J41:329727	ORC	830614		R
71710	Kakanui	Pringles	J42:427581	ORC	820630	940630	R
71713	Kakanui	Mill Dam	J42:404593	ORC	891218		R
72004	Waiarakarua	D/S Confluence	J42:401477	NIWA-Dun	690717	740902	N
72601	Shag	Dunback Domain	I42:249324	ORC	71	900329	R
72603	Shag	The Grange	I42:232357	ORC	891011		R
72627	Deepdell Ck	Golden Point Rd	I42:080366	ORC	850731		R
73103	Waikouaiti Nth	Bucklands Crossing	I43:214087	ORC	910130		R
73105	Waikouaiti Sth	Lawsons	I43:196044	ORC	910205		R
73501	Leith	University Foot Br	I44:169798	ORC	611107		R
73502	Leith	George St	I44:168808	ORC	610714		R
73508	Lindsays CK	Bonnington St	I44:189823	ORC	791003	900412	R
73510	Otago Harbour	Harbour Bd Office	I44:163779	POL	80		R
74301	Taieri	Taieri Mouth	I45:925580	NIWA-Dun	881129	940111	N
74302	Taieri	Henley Ferry Br	H45:890646	ORC	690620		R
74303	Owhiro Stm	OSGOS	I44:979742	ORC	851223		R
74306	Taieri	Cashmeres	I44:961734	ORC	780609	930630	R
74308	Taieri	Outram	I44:958810	ORC	581103		R
74309	Taieri	Hindon	I44:030961	ORC	720224	870714	R
74310	Taieri	Sutton	H43:867116	ORC	600825		R
74311	Taieri	Tiroiti	I42:959466	ORC	680718		NR
74312	Taieri	Peddies Pump	I42:955388	ORC	920423		R
74313	Taieri	Waipiata	H42:863529	NIWA-Dun,ORC	670504		NR
74314	Taieri	Hores Br	H42:712380	NIWA-Dun	670208		N
74315	Taieri	McAtamneys	H43:717292	NIWA-Dun	770929		N
74316	Taieri	Paerau	H43:707277	NIWA-Dun	580403	670418	N

74317	Taieri	Halls Br	H42:766513	ORC	800409	900724	R
74318	Taieri	Canadian Flat	H43:551135	NIWA-Dun	821127		N
74319	Taieri	Below Patearoa P/S	H42:712380	NIWA-Dun	840418		N
74320	L Waipori	Waipori Pump	H45:874671	ORC	630509		R
74321	Waipori	Berwick	H45:851696	ORC	681104		R
74324	Silverstream	Taieri Depot	I44:021783	ORC	860617		R
74326	Silverstream	Gordon Rd	I44:036788	ORC	75	87	R
74327	Lee Stm	Outram Hindon	I44:973874	ORC	750917	860124	R
74329	Contour Channel	Dow Rd	I44:918774	ORC	791219		NR
74331	Nenthorn	Mt Stoker Rd	H43:879157	ORC	821103		R
74332	Taieri	Loganburn Ford Rd	H43:662252	NIWA-Dun	910301		N
74337	Kyeburn	SH85	I42:946585	ORC	680109		R
74338	Sutton Stm	SH 87	H43:832084	NIWA-Dun	860226		N
74346	Loganburn	Paerau	H43:668236	NIWA-Dun	660228	800611	N
74347	Loganburn	Gorge	H43:671233	NIWA-Dun	800702	900327	N
74349	Loganburn Res	Dam	H43:697164	NIWA-Dun	851024	901129	N
74350	Deep Stm	DCC Weir	H44:730989	ORC	330101		NR
74351	Deep Stm	Totara Rock	H44:680993	NIWA-Dun	760402	851214	N
74352	Deep Stm	Rocklands	H44:715993	NIWA-Dun	691216	770428	N
74353	Gimmerburn	Rough Ridge	H42:667589	NIWA-Dun	710818	940112	N
74354	L Waihola	Waihola	H45:835607	ORC	650819		NR
74355	Deep Stm	Dunstan Track	H44:750994	ORC	840918	92	R
74357	Deep Stm	SH87	H44:803973	ORC	911217		R
74360	Kintore Ck	Berridale	H45:762607	NIWA-Dun	780718	940111	N
74361	Jura Ck	Jura Rd	H45:774652	NIWA-Dun	780621	870714	N
74362	Storm Ck	Storm Rd	H45:790659	NIWA-Dun	780705	870714	N
74363	Tussockburn	Old Mine	H44:577854	NIWA-Dun	790401	860128	N
74364	Vollweillerburn	Berridale	H45:763606	NIWA-Dun	800529	870714	N
74365	Anonymous Ck	Mahinerangi	H44:768846	NIWA-Dun	781228	860128	N
74366	Eighty Ck	School Rd	H44:841889	NIWA-Dun	781228	860128	N

74367	Deep Ck	Muster Huts	H44:590970	NIWA-Dun	790507	940112	N
74368	Elbow Ck	Muster Huts	H44:558969	NIWA-Dun	790507		N
74369	Poisonous Ck	Lammermoor Rd	H43:663046	NIWA-Dun	790605	860117	N
74370	Sentinel Ck	Sentinel Rocks	H43:669104	NIWA-Dun	790501	860117	N
74382	Owhiro Stm	Gladfield Rd	I44:010755	ORC	851218	920814	R
74392	Kyeburn	Danseys Pass	I41:992794	NIWA-Dun	900502		N
74393	Timber Ck	Danseys Pass	I41:993796	NIWA-Dun	900502		N
74394	Kyeburn	Danseys Hotel	I41:960763	NIWA-Dun	930713		N
74701	Nobles Stm	Bull Ck Rd	H45:825450	NIWA-Dun	700608		N
74810	Tokomairiro	Listnatunny	H45:748528	ORC	80	89	R
74811	Tokomairiro	West Branch Br	H45:661540	ORC	811217		R
75201	Clutha Koau	Inchclutha Pumps	H46:639252	ORC	731108		R
75202	Clutha Matau	Rutherford Locks	H46:650271	ORC	890213		R
75203	Inchclutha Pump	Rutherfords	H46:651271	ORC	881013		R
75205	Clutha	Kaitangata Locks	H46:665313	ORC	720418		R
75206	Kaitangata Channel	Kaitangata Locks	H46:665313	ORC	720418		R
75207	Clutha	Balclutha	H46:590362	ORC,NIWA-Dun	540707		NR
75208	Kaitangata Drain	Kaitangata Pump	H46:665313	ORC	720706		R
75209	L Tuakitoto	Outlet	H46:653366	ORC	611205		R
75211	Clutha	ORC, Balclutha	H46:592362	ORC	540706		R
75216	Puerua	Paratai Pump	H46:605247	ORC	881013		R
75229	Waitahuna	Tweeds Br	H45:541597	ORC	860731		R
75231	Pomahaka	Burkes Telemetry	G45:314549	ORC	880731		R
75232	Pomahaka	Burkes Ford	G45:314549	NIWA-Dun	610804		N
75234	Pomahaka	Glenken	G44:105754	ORC	860630		R
75237	L Onslow	Dam	G43:440119	NIWA-Alx	740131	860131	N
75251	Manuherikia	D/S Forks	H40:650006	NIWA-Alx	750528	940121	N
75252	Poolburn	Cob Cottage	H41:521684	ORC	890315	940630	R
75253	Manuherikia	Ophir	G41:418608	NIWA-Alx	710201		N
75254	Clutha	Suttons	G42:225491	NIWA-Alx	860702		N

75255	Dovedale Ck	Willows	H42:531517	ORC	730109	870930	NR
75256	Woolshed Ck	Lauder Stn	H41:509817	ORC	721214	89	R
75257	Dunstan Ck	Gorge	H40:545947	ORC	730307	940630	R
75258	Idaburn N Branch	Race	H41:729836	NIWA-Alx	730430	841003	N
75259	Fraser	Old Man Range	G42:122472	NIWA-Alx	690527	940121	N
75261	Fraser	Laing Rd	G42:212476	NIWA-Alx	831031		N
75262	Kawarau	Chards Rd	F41:844698	NIWA-Alx	621122		N
75263	Kawarau	Frankton	F41:740667	NIWA-Alx	630202		N
75265	Nevis	Wentworth Stn	F41:974639	NIWA-Alx	770407	900703	N
75271	Mill Ck	Fish Trap	F41:799739	ORC	830330		R
75272	Arrow	Beetham Ck	F41:829745	NIWA-Alx	810415	940124	N
75273	Arrow	Tobins Track	F41:819770	NIWA-Alx	740307	820312	N
75274	Shotover	Campbells Saddle	F40:722957	NIWA-Alx	750410	801125	N
75275	Shotover	16 Mile	E40:658065	NIWA-Alx	770216	841212	N
75276	Shotover	Bowens Peak	F41:722710	NIWA-Alx	670629		N
75277	L Wakatipu	Recorder	F41:733668	NIWA-Alx	621128		N
75278	Shotover	16 Mile Gorge	E40:649069	NIWA-Alx	770909	860423	N
75279	Shotover	Strohlers	F40:731935	NIWA-Alx	791212	870620	N
75282	Clutha	Cardrona Confluence	F40:088066	NIWA-Alx	880315		N
75287	Hawea	Camphill Br	G40:124107	NIWA-Alx	680306		N
75288	L Hawea	Dam	G40:125153	NIWA-Alx	670401		N
75290	Cardrona	Albert-town	F40:079064	NIWA-Alx	780928		N
75292	L Wanaka	Recorder	F40:037058	NIWA-Alx	330201		N
75293	Cardrona	Mt Barker	F40:029993	ORC	761201	920317	R
75294	Matukituki	West Wanaka	F40:920114	NIWA-Alx	790821		N

SOUTHLAND

75213	Clutha	Clyde	G42:212502	NIWA-Alx	590801		N
75214	Clutha	Lowburn	G41:121708	NIWA-Alx	671115	920116	N
75219	Lindis	Lindis Peak	G40:333019	NIWA-Alx	760924		N
75221	Clutha	Above Clyde Divers	G42:198520	NIWA-Alx	860619	920226	N

75228	Clutha	Alexandra Br	G42:266438	NIWA-Alx	891020		N
77502	Mataura	Wyndham	F46:886235	SRC	881117		R
77504	Mataura	Gore HBr	F45:967489	SRC	600722		NR
77505	Mataura	Parawa	E43:635073	SRC	551206		NR
77506	Mataura	Tuturau	F46:895333	SRC	820921		NR
77518	Mataura	Mataura Island	F46:849158	SRC	731005	800618	NR
77519	Mataura	Seaward Downs	F46:866160	SRC	800617		NR
77520	Mataura	Pyramid Br	F45:851692	SRC	740222		NR
77521	Mataura	Fairlight	F43:716230	SRC	620802		R
77522	Mataura	Keowns Rd	F44:720804	SRC	740419	820929	NR
77523	Waikaka	Willowbank Br	F45:032564	SRC	750222	830822	NR
77525	Waimea	Mandeville Br	F45:846607	SRC	741219		NR
77526	Wyndham Stm	Glenham Br	F46:903205	SRC	741219	810713	NR
77527	Wyndham Stm	McKays	F46:913198	SRC	810320		NR
77528	Waikaka Stm	Craigie Rd	F45:018545	SRC	830322		NR
77561	Waikaia	Mahers Beach Rd	F44:842862	SRC	770414		NR
77562	Waikaia	Waikaia Br	F44:862901	SRC	631001		R
77563	Waikaia	Piano Flat	F43:983079	SRC	790716		NR
77564	Mataura	Cattle Flat	F44:727900	SRC	890323		R
78503	Waihopai	Kennington	E46:596146	NIWA-Dun,SRC	580631	780714	NR
78504	Waihopai	Above Scour	E46:605145	SRC	761004		NR
78601	Oreti	Riverton Hy Br	E46:454208	SRC	771005		NR
78602	Oreti	McKellar's Flat	E42:345315	SRC	770308	861028	NR
78607	Oreti	Lumsden	E44:541892	SRC	550803		not
78608	Oreti	Three Kings	D43:296177	SRC	860724		NR
78612	Dunsdale	Weir	F45:703432	SRC	441231	540823	NR
78625	Otapiri	McBrides Br	E45:581577	SRC	631224		NR
78626	Winton Stm	Thomsons Crossing	E46:484369	SRC	740226	870129	NR
78630	Waikiwi Stm	Ferry Rd	E46:455137	SRC	881128		R
78633	Makarewa	Freezing Works Br	E46:504231	SRC	661101	810508	NR

78634	Makarewa	Counsell Rd	E46:534232	SRC	810922		NR
78635	Makarewa	Tussock Ck	E46:595283	SRC	881215		R
78636	Oreti	Lumsden Cableway	E44:535908	SRC	760331		NR
78637	Irthing Stm	Ellis Rd Br	E44:535934	SRC	760510		NR
78803	Middle Ck	Otahuti	E46:375346	SRC	691222		NR
78901	Aparima	Thornbury Br	E46:311244	SRC	850306		NR
78904	Otautau Stm	Otautau	D46:230400	SRC	881019		R
78905	Aparima	Yellow Bluffs Br	D45:238410	SRC	780127		NR
78906	Aparima	Dunrobin	D44:299855	SRC	780831		NR
78910	Hamiltonburn	Matuku Br	E44:356875	SRC	750501	841018	NR
78912	Hamilton Burn	Waterloo Rd	E44:345883	SRC	840725		NR
78915	Aparima	Etalvale	E44:318728	SRC	880920		R
79701	Waiau	Tuatapere	D46:994398	NIWA-Dun	640729		N
79702	Waiau	Te Waewae Lagoon	D46:959313	NIWA-Dun	681231	900911	NR
79703	Waiau	L Manapouri	C43:893018	NIWA-Dun	320501	760523	N
79704	Waiau	L Te Anau	D43:968185	NIWA-Dun	320301		N
79706	L Manapouri	West Arm	C43:630050	NIWA-Dun	890223		N
79707	L Manapouri	Supply Bay	C43:885062	NIWA-Dun	760219		N
79708	Waiau	Queens Reach	D43:947121	NIWA-Dun	760303		N
79709	L Te Anau	Glade House	D41:099739	NIWA-Dun	911127		N
79712	Monowai	Below Control Gates	C44:853751	NIWA-Dun	760902		N
79713	L Monowai	Hincheys Outlet	C44:845744	NIWA-Dun	770513		N
79714	Monowai	Above Powerhouse	C44:896780	NIWA-Dun	670518	771012	N
79718	Waiau	Manapouri Struct HW	D44:962969	NIWA-Dun	770930		N
79719	Waiau	Manapouri Struct TW	D44:962969	NIWA-Dun	770921		N
79720	Waiau	Manapouri Channel	D44:951976	NIWA-Dun	771117		N
79730	Waiau	Monowai Powerhouse	D44:916790	NIWA-Dun	670518	730221	N
79732	Waiau	U/S Mararoa	D44:954974	NIWA-Dun	650807	790510	N

79734	Waiau	Excelsior Ck	D44:959958	NIWA-Dun	720705	810708	N
79735	Waiau	Sunnyside	D44:934764	NIWA-Dun	720210		N
79737	Mararoa	At Cliffs	D44:968979	NIWA-Dun	760415		N
79740	Spey	West Arm, L Manapouri	C43:625045	NIWA-Dun	911209		N
79798	Waiau	Clifden	D45:011511	SRC	890419		R
80201	Rowallanburn	Old Mill	C46:879382	SRC	691219		NR
80901	Wairaurahiri	L Hauroko	C45:680432	NIWA-Dun	670517		N
81301	Waitutu	L Poteriteri	C46:540309	NIWA-Dun	670814	780119	N
84701	Cleddau	Milford	D40:086023	NIWA-Dun	630115	800617	N

WESTLAND

86301	Arawata	County Br	E38:675759	NIWA-Gym	880323		N
86802	Haast	Roaring Billy	G37:129895	NIWA-Gym	690612		N
87301	Moeraki	L Moeraki	G36:106135	NIWA-Gym	761105		N
87801	Makawhio	Rocks	G36:425314	NIWA-Gym	861211		N
89103	L Wahapo	Lake	H35:872692	WCRC	671122	910621	NR
89201	Waitangi-Roto	Heron Colony	H34:853814	NIWA-Gym	701124	760707	N
89202	Waitangi-Roto	Mid Roto	I34:913798	NIWA-Gym	710909	760929	N
89203	Waitangi-Taona	Ford	I34:957774	NIWA-Gym	720519	771231	N
89301	Whataroa	SHB	I35:994656	NIWA-Gym	851216		N
90101	Waitaha	SHBr	I33:213004	NIWA-Gym	771219	840410	N
90102	Ivory	Ripplerock	J34:402838	NIWA-Gym	710402	810331	N
90604	Hokitika	Colliers Ck	J33:465004	NIWA-Gym	710524		N
90605	Butchers Ck	L Kaniere Rd	J33:534242	NIWA-Gym	710715	940127	N
90607	Cropp	Gorge	J34:443902	NIWA-Gym	791211		N
91101	Taramakau	Gorge	J32:654374	NIWA-Gym	690423	790820	N
91103	Taipo	SHBr	K33:794266	NIWA-Gym	780508		N
91104	Taramakau	Greenstone Br	J32:622403	NIWA-Gym	790130		N
91401	Grey	Dobson	J31:700601	NIWA-Gym	680724		N
91404	Grey	Waipuna	L31:100720	NIWA-Gym	690311		N
91405	Arnold	L Brunner	K32:844467	NIWA-Gym	680215		N

91407	Ahaura	Gorge	K31:055632	NIWA-Gym	680508		N
91411	Pattinson Ck	Weir Site 1	K30:092960	NIWA-Gym	781214	860709	N
91412	Pattinson Ck	Weir Site 2	K30:092960	NIWA-Gym	781214		N
91413	Pattinson Ck	Weir Site 3	L30:100963	NIWA-Gym	781219	860723	N
92602	Tiropahi	SHB	K30:793156	NIWA-Gym	851212		N
92801	Nile	Below Awakari	K30:833197	NIWA-Gym	771223	911128	N
93203	Buller	Te Kuha	K29:020295	NIWA-Gym	630729		N
93204	Buller	Berlins	L29:147277	NIWA-Gym	520303	700311	N
93206	Inangahua	Landing	L29:182212	WCRC	631128		N
93207	Inangahua	Blacks Pt	L30:172976	NIWA-Gym	650514		N
93208	Buller	Woolfs	L29:261297	NIWA-Gym	631017		N
93602	Waimangaroa	Smokestack	L29:131392	NIWA-Gym	740618	880421	N
93901	Ngakawau	Lineslip	L28:177548	NIWA-Gym	740607	910808	N
93902	T35	Mt Stockton	L29:191485	NIWA-Gym	760325	820315	N
94302	Mokihinui	Burkes Ck	L28:274604	NIWA-Gym	720309	801003	N
94303	Mokihinui	Welcome Bay	L28:292609	NIWA-Gym	790927	931231	N
95101	Karamea	Arapito	L27:404932	NIWA-Gym	700826	790312	N
95102	Karamea	Gorge	L27:446944	NIWA-Gym	770620		N

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