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Flow regime requirements for instream ecology in the Waihou River catchment - Waihou catchment ecological monitoring 2009

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NIWA Client Report: HAM2009-089
June 2009

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Executive Summary

Environment Waikato (EW) is currently in the process of reviewing the status of water resource availability and allocation in the Waihou River catchment. Traditionally, water allocation rules have been based on the establishment of minimum flows required to sustain selected ecological values. However, as pressure on water resources increases and knowledge regarding the flow requirements of aquatic ecosystems improves, it is recognised that the establishment of minimum flows may be insufficient for adequate protection of water resources.

This study investigates the role of flow variability for instream ecology in the Waihou River catchment. The purpose of the study is to supplement the initial minimum flow study in order to provide a more holistic framework for defining flow requirements for protecting instream ecology. The Range of Variability Approach (RVA) has been applied to the Waihou catchment to support development of flow allocation rules by Environment Waikato. A range of hydrologic parameters representing different components of the flow regime have been calculated from available hydrologic data, providing information on the natural range of flow variability across the catchment.

A range of flow types were identified within the Waihou catchment. The upper catchment is characterised by stable flows with a high proportion of baseflow, the middle and lower Waihou are also strongly influenced by the high level of baseflow in the upper catchment, but superimposed upon this are the effects of the more flashy streams draining the Kaimai and Coromandel Ranges. The Ohinemuri sub-catchment is extremely dynamic, with a flow regime strongly driven by surface water inputs and characterised by low baseflows and a high frequency of flood events.

It is suggested that ecological communities in areas with stable flow are most susceptible to changes in flow regime. Communities established in stable environments are typically less well adapted to extreme variations in flow. Consequently, these environments may require a greater level of protection than streams with frequent, high levels of disturbance. However, evidence also suggests that fish communities within New Zealand are fairly similar across a wide range of different flow regimes. This suggests the existence of ecological redundancy in relation to flow requirements for fish, which may offer the opportunity for exploitation of some components of the flow regime for other uses. However, the amount of hydrological variation required to maintain a healthy ecosystem is poorly understood and the complexity of natural systems makes it difficult to define thresholds at which the flow regime will maintain a desired river condition as evidenced by this assessment of the Waihou catchment.

Ideally, the RVA is employed when comparing natural and alternative managed flow scenarios by quantifying hydrological alteration in comparison to natural variability. This was not possible for this project as only historical records were available. However, the RVA results can be used as a baseline to inform flow management decisions and assess the impact of proposed changes in allocation rules.

1. Introduction

1.1 Background

Environment Waikato (EW) is currently in the process of reviewing the status of water resource availability and allocation in the Waihou River catchment. One of the key objectives of the water allocation process is to ensure the protection of instream values from the effects of water resource exploitation. Jowett (2008) identified minimum flow requirements for fish habitat in the Waihou River and selected tributaries. The establishment of minimum flows may be the first stage in protecting instream values. However, it is increasingly recognised that defining ecological flow requirements solely in terms of a minimum flow and fish habitat is insufficient for meeting the needs of the entire riverine ecosystem and it is now increasingly acknowledged that a naturally variable regime of flow is required to sustain these systems. As pressure on water resources increases, water users begin to look at exploiting other parts of the flow regime, particularly small floods and flushing flows, to provide for their water needs. These components of the flow regime can be important for maintaining a number of ecological functions in rivers. This is therefore leading to a demand for more holistic approaches to setting ecological flow requirements, which incorporate aspects of the whole flow regime and wider range of ecological functions.

1.2 Study brief

The overall aim of this study was to characterise and investigate the role of flow variability for fish populations in the Waihou River catchment. The purpose is to supplement the initial minimum flow study (Jowett, 2008) in order to provide a more holistic framework for defining flow requirements and to protect instream ecology.

The scope of the project was to:

- characterise flow regimes at a range of sites throughout the catchment to establish a baseline status;
- identify and quantify the degree of flow modification in the catchment if present;
- identify suitable sites for establishing long term monitoring of fish and macroinvertebrate populations and carry out baseline fish/macroinvertebrate surveys at these sites;
- investigate the composition of ecological communities across the range of flow regimes present within the catchment.

2. Defining environmental flow requirements

The development and management of water resources by humans can alter the natural flow patterns of rivers, with consequential impacts on river biota (Petts and Maddock, 1994; Poff et al. 1997). For example, it is possible that modification of the timing, frequency or duration of floods can eliminate spawning or migratory cues for fish; increased frequency or duration of high flows may displace velocity-sensitive species; and increased frequency and duration of low flows may increase sediment deposition, smothering deposited eggs (Bunn and Arthington, 2002). Consequently, there is growing recognition and acceptance that rivers and their associated biota are legitimate ‘users’ of freshwater and that they require ample water to maintain essential ecosystem goods and services (Arthington et al. 2006; Baron et al. 2002; Postel and Richter, 2003).

The allocation of water for environmental or ecological needs has increasingly become a key element of integrated water resources management. Historically, the provision of ‘environmental flows’ has frequently been equated to ‘ecological flows’ i.e., the quantity of water required to sustain instream ecological values. However, the concept of environmental flows has now grown to encompass a broader range of values; of which ecological flows is only one component. The New Zealand Ministry for the Environment states that environmental flows may provide for ecological, tangata whenua, cultural, recreational, amenity, landscape and natural character values associated with a particular water body (MfE, 2008). The values provided for, and the level of protection afforded to each, will depend on the characteristics of an individual water body and may be determined in a variety of ways.

Methods for estimating the environmental flow requirements for rivers have traditionally focussed on one or a few species, with the intent of establishing the minimum allowable flows (Acreman and Dunbar, 2004; Jowett, 1997; Jowett and Biggs, 2008; Poff et al. 1997; Tharme, 2003). The Physical Habitat Simulation (PHABSIM) system (Bovee, 1982) was the first systematic modelling framework to be developed for determining ecological flow requirements. The equivalent in New Zealand is RHYHABSIM (Jowett, 1996), which has now been applied to many rivers throughout the country. These models quantify the relationship between the quantity of physical habitat, defined in terms of the combination of depth, velocity and substrate, and flows. A key criticism of this approach is the lack of biological realism (Hudson et al. 2003; Orth and Maughan, 1982). Increasingly it has also been recognised that physical habitat approaches often focus on one or a few species, and that setting a single minimum flow fails to recognize that what is good for individual species may not be of benefit to the ecosystem, and what is good for the ecosystem may not consistently benefit individual species (Arthington et al. 2006; Poff et al.

1997). Subsequently, more holistic approaches targeting preservation of aquatic species at the community level and recognising the importance of flow variability have developed (Acreman and Dunbar, 2004; Arthington et al. 2006; Richter et al. 1997).

The flow regime of a river has been called a master variable that limits the distribution and abundance of riverine species and regulates the ecological integrity of flowing water systems (Poff et al. 1997). Numerous flow characteristics are presumed to be important for the maintenance and regeneration of riverine habitats and hence for biological diversity (Bunn and Arthington, 2002; Poff and Ward, 1989; Richter et al. 1997). These characteristics can be defined by five critical components: magnitude, frequency, duration, timing and rate of change of hydrologic conditions (Poff et al. 1997; Richter et al. 1996). Although possible functions of different flow regime components have been identified, the degree to which the frequency and duration of these events affects biota is not well understood and there is currently no quantitative method of assigning acceptable frequencies and durations, other than to mimic nature. The natural flow paradigm suggests that the full range of natural intra- and inter-annual variation in flow characteristics is critical in sustaining the full native biodiversity and integrity of aquatic ecosystems (Poff et al. 1997; Richter et al. 1997). This is because native riverine species develop life history traits that enable individuals to survive and reproduce within a certain range (i.e., the natural range) of environmental variation (Stanford et al. 1996; Townsend and Hildrew, 1994) and departure from this can result in community change and a loss of biodiversity.

A number of holistic flow assessment frameworks aligned with the natural flow paradigm have consequently emerged (Tharme, 2003). The range of variability approach (RVA), and the associated indicators of hydrological alteration (IHA), characterises the ‘natural’ flow regime using a set of hydrological parameters and identifies the natural range of hydrological variability that exists (Richter et al. 1997). Flow guidelines are then designed to allow an appropriate range of variation, for example within one standard deviation of the mean where a parameter is normally distributed. The implicit assumption of this method is that the natural flow regime has intrinsic value or important ecological functions that will be maintained by retaining the key elements of the natural flow regime. A further development of this principle are the building block method (BBM) (King et al. 2008) and the flow events method (FEM) (Stewardson and Gippel, 2003), which are based on the concept that some flows within the complete hydrological regime are more important than others for the maintenance of the river ecosystem, and that these flows can be identified and characterised in terms of their magnitude, duration, timing and frequency. They take a prescriptive approach, identifying key components of the flow regime for protection and designing a flow regime to maintain a river in a particular condition. However, the amount of hydrological variation required to maintain a healthy ecosystem is poorly understood and the complexity of natural systems makes it difficult to define thresholds at which the flow regime will maintain a desired river condition (Acreman and Dunbar, 2004; Beca, 2008). Consequently a cautious approach to setting flows is required that builds buffers for risk and unknown outcomes.

The major challenge in defining environmental flow requirements is dealing with the uncertainties resulting from a combination of variability inherent in hydrological systems, scientific error and the subjective nature of assessments (MfE, 2008). The best approach to dealing with such uncertainty is to adopt a method that reflects the uncertainties and potential cumulative effects, and to follow a flexible, adaptive management approach which allows the incorporation of new information as it becomes available.

3. Methodology

3.1 Flow analysis

3.1.1 Background to the RVA

The Range of Variability Approach (RVA) that can be applied using the Indicators of Hydrological Alteration (IHA) (Richter et al. 1996; The Nature Conservancy, 2007) is one method for describing the hydrological characteristics of a river. This method has been applied in Canada (Bradford et al. 2007), South Africa (King et al. 2003), Taiwan (Shiau and Wu, 2004), the UK (Black et al. 2002) and the US (e.g., Richter et al. 1998). Although the RVA has not routinely been applied in New Zealand, it is included in the National Environmental Standards (NES) schedule of methods for rivers with a high significance of instream values (Beca, 2008). The draft guidelines for selection of methods to determine ecological flows state that “while analysis of hydrological variation will not by itself allow the setting of ecological flows, it will act as a ‘flag’ to other methods to illustrate the extent of hydrological change, and how these hydrological parameters may be affected by the ecological flow decision” (Beca, 2008).

The RVA method requires a time-series of flows for the river or site under investigation. A set of statistical parameters are used to characterise hydrological conditions in each year of the time-series. These parameters provide information designed to describe fully the natural flow regime, including those components that are ecologically significant. Measures of spread are then used to quantify the variation in these parameters between years. Different measures of spread can be employed depending on whether it is assumed that the data are paraparameterally or non-paraparameterally distributed. The parameters and their range of variability are “intended for use with other [unspecified] ecosystem parameters” in order to inform management activities and for setting environmental flow regimes (Richter et al. 1996). Potential ecosystem influences associated with different parameters are shown in Table 3.1. Where pre-impact and post-impact flow data are available, the degree of hydrological alteration can be assessed by comparing distributions drawn from annual time-series for each scenario and for each of the parameters.

Table 3.1: Summary of hydrologic parameters and their ecosystem influences. Adapted from IHA user's manual (The Nature Conservancy, 2007).

IHA parameter group	**Hydrologic parameters**	**Ecosystem influences**
1. Magnitude of monthly water conditions	Mean/median flow for each month	• Habitat availability for aquatic organisms • Water quality • Connectivity between habitats • Reliability of water supply for terrestrial flora & fauna
2. Magnitude and duration of annual extreme water conditions	Annual 1-day mean minima & maxima Annual 3-day mean minima & maxima Annual 7-day mean minima & maxima Annual 30-day mean minima & maxima Annual 90-day mean minima & maxima Number of zero-flow days Base flow index (BFI)	• Balance of competitive, ruderal & stress-tolerant species • Structure of river channel morphology & physical habitat • Nutrient exchange between river & floodplain • Duration of stressful conditions • Sediment dynamics • Connectivity between river & floodplain habitats
3. Timing of annual extreme water conditions	Julian date of each annual 1-day minimum and maximum flow	• Predictability of disturbance/stress • Compatibility with life cycles of organisms • Spawning cues for migratory fish • Evolution of life-history strategies & behavioural mechanisms
4. Frequency and duration of high and low pulses	Number of low & high flow pulses in each water year Mean/median duration of low & high pulses	• Frequency & duration of stress • Availability of & access to habitats • Nutrient & organic matter exchange • Sediment dynamics
5. Rate and frequency of water condition changes	Rise rates: Mean/median of all positive differences between consecutive daily values Rise rates: Mean/median of all negative differences between consecutive daily values Number of hydrologic reversals	• Stranding/entrapment of organisms • Desiccation stress on low-mobility stream edge organisms

3.1.2 RVA method

A range of hydrological parameters were calculated from daily flows for each year from each site (Table 3.2) following the methods of Richter et al. (1996; 1997) and The Nature Conservancy (2007). Low and high pulse events are defined as those events with a peak flow greater than the 75th or 25th flow exceedance percentiles respectively. Hydrologic reversals are when flow shifts between positive and negative differences between days. Years with more than 50 days of missing records were removed from the analysis. The number of days in each year for which data were unavailable was also calculated.

Shapiro-Wilk tests for normality (Royston, 1995) were applied to assess normality within the distributions of:

- the within month daily flows;
- the duration of each low pulse within each year;
- the duration of each high pulse within each year;
- the positive differences between daily values within each year; and
- the negative differences between daily values within each year.

For each of the parameters that describe the hydrological conditions in each year, the normality test was used to indicate whether the mean value was representative of the central tendency. In the case of normal distributions the mean and median will be the same. In non-normal (non-parametric) situations mean values may not represent central tendency, as they may be strongly affected by a small number of extreme events. For this analysis it was assumed that the medians of the daily flows in each month were adequate to represent seasonal flow patterns. It was assumed that median values for durations of high and low pulses adequately represented the durations of high and low pulses. It was also assumed that median values for positive daily difference and negative daily differences adequately represented the rates of flow changes. Therefore, 35 parameters were selected, which together were then used to describe the hydrological conditions in each year of record for each site.

The annual time-series for each of these 35 parameters was assessed for trend and serial dependence. The presence of statistically significant trends in time within each time-series was assessed by applying linear regressions against year for records greater than 5 years in length. Parameters with p-values less than 0.05 for the slope in this relationship were deemed to have statistically significant trends in time. The presence of serial dependence within each time-series was tested by calculation of both autocorrelation and partial autocorrelation. Significance was assessed at the 95% confidence interval. Time-series analyses such as these assume the data are untrended and stationary. This can be interpreted as meaning that the time-series has the same properties wherever in the sequence you start looking at it.

Table 3.2: Calculated hydrological parameters. Those highlighted in bold are the parameters selected for the analysis.

Group	Parameter description	n
1) Magnitude of monthly water flows	Mean value for each calendar month*	24
	Median value for each calendar month*	
2) Magnitude and duration of annual extreme flows	**Annual minima 1-day means***	12
	Annual minima 3-day means*	
	Annual minima 7-day means*	
	Annual minima 30-day means*	
	Annual minima 90-day means*	
	Annual maxima 1-day means	
	Annual maxima 3-day means	
	Annual maxima 7-day means	
	Annual maxima 30-day means	
	Annual maxima 90-day means	
	Number of zero flow days*	
	Base flow index: 7-day minimum flow/ mean flow for year*	
3) Timing of annual extreme flows	**Julian date of annual 1-day minimum***	2
	Julian date of annual 1-day maximum	
4) Frequency and duration of high and low pulses	**Number of low pulses within each water year***	6
	Mean duration of low pulses*	
	Median duration of low pulses*	
	Number of high pulses within each water year	
	Mean duration of high pulses	
	Median duration of high pulses	
5) Rate and frequency of flows changes	Mean of all positive differences between daily values*	7
	Median of all positive differences between daily values*	
	Number of all positive differences between days*	
	Mean of all negative differences between daily values*	
	Median of all negative differences between daily values*	
	Number of all negative differences between days*	
	Number of hydrologic reversals	

* = relevant to low flow analysis.

3.1.3 Extension of flow records

In an attempt to extend the RVA analysis to a wider range of sites, correlations in daily flow between sites with short and long records were investigated. If sufficiently good correlations existed, there was a possibility that the shorter flow records could be synthetically lengthened to increase the number of sites to which the RVA analysis could be applied.

3.1.4 Sites

Sites were selected for inclusion in the flow analysis based on the length of record and their spatial distribution. Length of record is particularly important for estimation of the hydrologic parameters. Kennard et al. (2009) evaluated the impact of differing record length on the precision of hydrologic parameters. They found that parameter bias rapidly decreased, and precision and overall accuracy markedly improved, with increasing record length. A minimum of fifteen years of discharge record was recommended as suitable for use in hydrologic analyses that aim to detect spatial/temporal differences in hydrologic characteristics (Kennard et al. 2009).

Within the Waihou catchment there are only six sites with flow records greater than 15 years in length. These sites consequently became the focus of the flow analysis. Three additional sites with records of approximately 10 years were also included in some of the analyses for improved spatial coverage. The details of the nine sites are included in Table 3.3 and their locations shown in Figure 3.1.

Table 3.3: Location of flow gauging sites used for flow analysis.

Flow gauge number	River	Location	Easting	Northing	Record length (Years)
1122.34	Waihou	Te Aroha	2749400	6402600	42
1122.38	Waihou	Tirohia	2743700	6414800	41
619.16	Ohinemuri	Karangahake	2750600	6417200	40
669.13	Oraka	Pinedale	2756300	6344600	28
1122.18	Waihou	Okauia	2760200	6375600	25
619.19	Ohinemuri	Queen’s Head	2757600	6417000	23
1122.30	Waihou	Shaftesbury	2754900	6393400	10
619.11	Ohinemuri	Frendrups	2764100	6419400	10
1158.3	Waimakariri	273 Waimakariri Road	2760600	6350700	9

Figure 3.1: Location of flow gauging sites used for this study.

3.2 Instream ecology

3.2.1 Sites

Eight sites were selected within the Waihou River catchment for the ecological surveys of fish, macroinvertebrates and macrophytes (Table 3.4; Figure 3.2). The sites were selected in consultation with EW staff on the basis of potential abstraction pressure, their representativeness of different river types within the catchment and ease of access for repeat monitoring. At six of the sites (Sites 3-8), paired surveys were carried out upstream and downstream of existing abstractions. The remaining two sites (Site 1 and 2) were located on lowland agricultural streams. Survey sites were concentrated in the middle and lower catchment where abstraction pressure is currently highest. It had been hoped to include sites on the Mangawhero Stream south of Matamata, but the nature of the stream (very high macrophyte density) made it impossible to carry out fish surveys by electric fishing.

Table 3.4: Details of the ecological survey sites in the Waihou River catchment.

Site	Stream	Easting*	Northing*	Comments
1	Depression Stream	2757273	6386560	Lowland agricultural stream
2	Karengorengo Stream	2758628	6384754	Lowland agricultural stream
3	Paiakarahi Stream	2751347	6429422	Upstream of public water supply abstraction
4	Paiakarahi Stream	2751431	6429122	Downstream of public water supply abstraction
5	Omahu Stream	2746560	6435409	Downstream of irrigation abstraction
6	Omahu Stream	2746688	6435516	Upstream of irrigation abstraction
7	Unnamed tributary of Homunga Stream	2765475	6420947	Downstream of irrigation abstraction
8	Unnamed tributary of Homunga Stream	2765847	6420687	Upstream of irrigation abstraction

* Easting and northing given for downstream limit of survey reach.

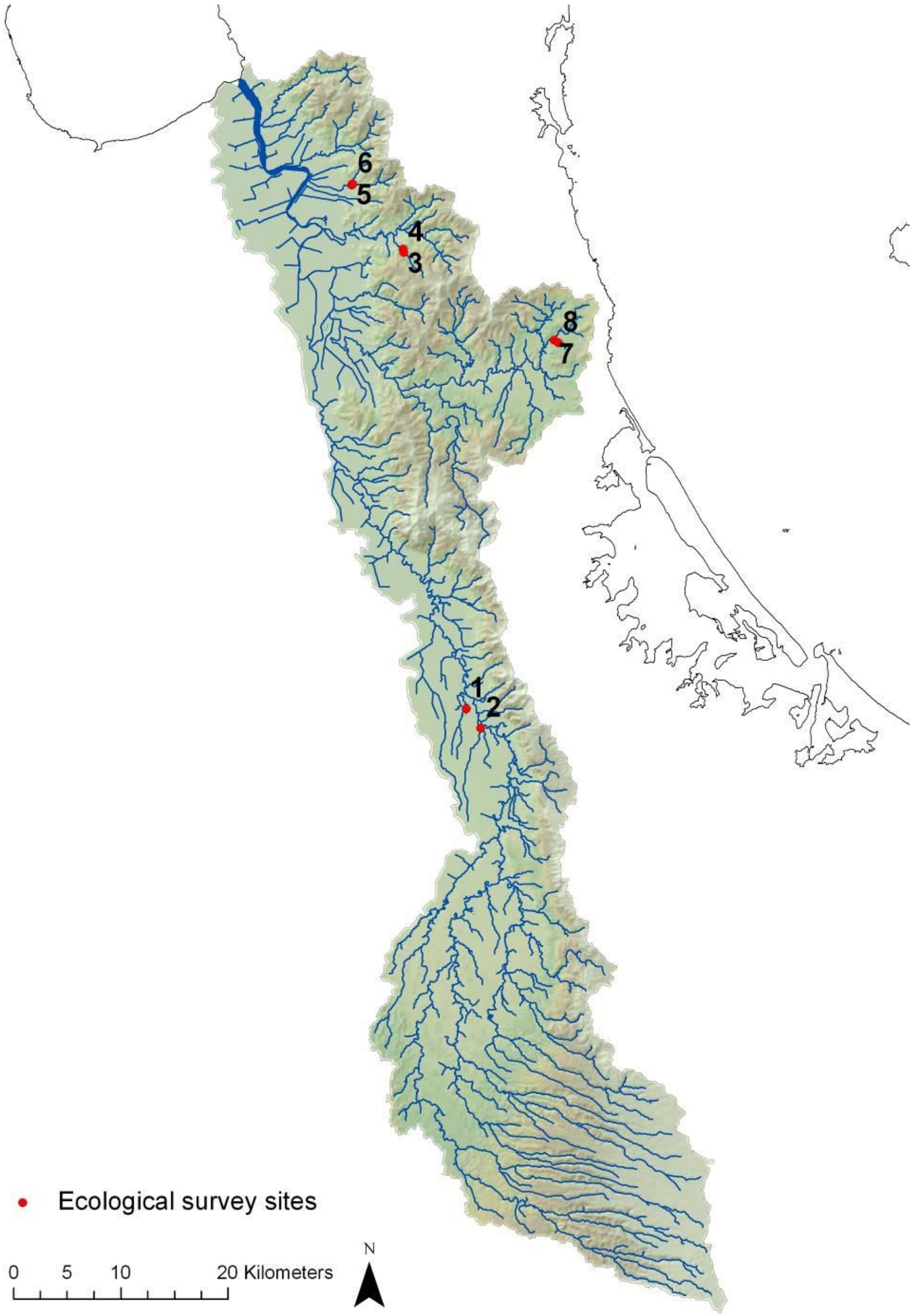

Figure 3.2: Location of ecological surveys carried out in the Waihou River catchment during this study.

3.2.2 Fish

Fish surveys were carried out by electric fishing using standardised methods as outlined by EW (and based on modified USEPA protocols) for wadeable streams. At each site, single pass electric fishing was carried out using an EFM300 with voltage adjusted dependent on local conditions, over a total reach length of 150 m. The abundance of each species captured was recorded, along with minimum and maximum fish lengths for every 15 m sub-reach. This survey approach is designed to maximise the likelihood of capturing the full diversity of species present by encompassing the range of habitats present within a stream. Results are also presented as a relative abundance standardised by survey area. Because these values are based on single pass electric fishing, which is a semi-quantitative method, these values are not equivalent to fish density and should not be used for comparison between sites. Interpretation of the relative abundance values should be restricted to temporal comparisons at the same site, assuming that the same reach is sampled, with the same level of effort and sampling efficiency on each sampling occasion.

3.2.3 Invertebrates

Macroinvertebrate sampling was carried out following the standardised procedures for wadeable streams as outlined by EW (Collier and Kelly, 2005). For hard-bottomed streams, a kick-sampling approach targeting riffle areas and following MfE Protocol C1 was utilised. In soft-bottomed streams, woody debris, macrophytes and stream banks were the targeted habitats and they were sampled using a hand net (0.5 mm mesh) following MfE Protocol C2. At each site the EW REMS habitat assessment protocol was also carried out, with a Field Assessment Cover Form and a Habitat Assessment Field Data Sheet completed. All samples were preserved and returned to the laboratory for processing.

Samples were processed using the recommended MfE Protocol P2 (200 individual fixed count and scan for rare taxa). This provides percent abundance data suitable for the calculation of most invertebrate parameters (Collier and Kelly, 2005).

3.2.4 Macrophytes

Macrophyte and periphyton surveys were carried out following the standardised procedures for wadeable streams as outlined by EW (Collier et al. 2006). Five evenly spaced transects were selected within the survey reach. At each transect periphyton cover was assessed at five points (10%, 30%, 50%, 70% and 90%) across the wetted width of the stream and the area of macrophyte cover occupying the 1 m wide band upstream of the transect was estimated. Details of the thickness and cover of periphyton were recorded allowing calculation of the Periphyton Enrichment Index (PEI) and a range of periphyton biomass indices (Collier et al. 2006). The percentage cover of different submerged and emergent species of macrophytes was also recorded, allowing calculation of the macrophyte cover indices (Collier et al. 2006).

4. Results

4.1 Flow regime

The analysis of flow regimes was focussed on the gauging sites with the longest records. The annual hydrographs over the complete time series available for each of the nine gauging sites selected are illustrated in Figure 4.1 to Figure 4.9. It can be seen that record length, the period covered and consistency of the flow records varies between the nine gauging sites. The longest (>40 yrs) and most complete records were for the Tirohia (Figure 4.1) and Te Aroha (Figure 4.2) sites on the Waihou River and the Karangahake site (Figure 4.7) on the Ohinemuri River, with records beginning in the 1960s and continuing to the present day. Consistent records of greater than 20 years are also available for the Waihou River at Okauia (Figure 4.4), the Oraka Stream at Pinedale (Figure 4.5) and the Ohinemuri River at Queen’s Head (Figure 4.8). The length of record at these six sites makes them suitable for calculation of the hydrologic parameters used in the RVA analysis. However, some caution must always be applied when analysing long term flow records due to the potential effects of changes in measurement methodology, precision and rating over time. In particular, the measurement accuracy of high flow events would have been limited in earlier years of the record due to limitations in gauging station ratings. Of the remaining three sites, only Shaftesbury (Figure 4.3) remains active, but an eleven year gap in the record between 1988 and 1999 limits our ability to robustly calculate the hydrological parameters for the RVA. The daily flow records for the Waimakariri Stream (Figure 4.6) and the Ohinemuri River at Frendrups (Figure 4.9) are also presented for comparison, but these gauges are no longer operational and the length of the records (<15 yrs) makes them unsuitable for RVA analysis. Also note that there were more than 50 days of missing data across the year for several years for the Ohinemuri River at Frendrups. These years were removed from the analysis.

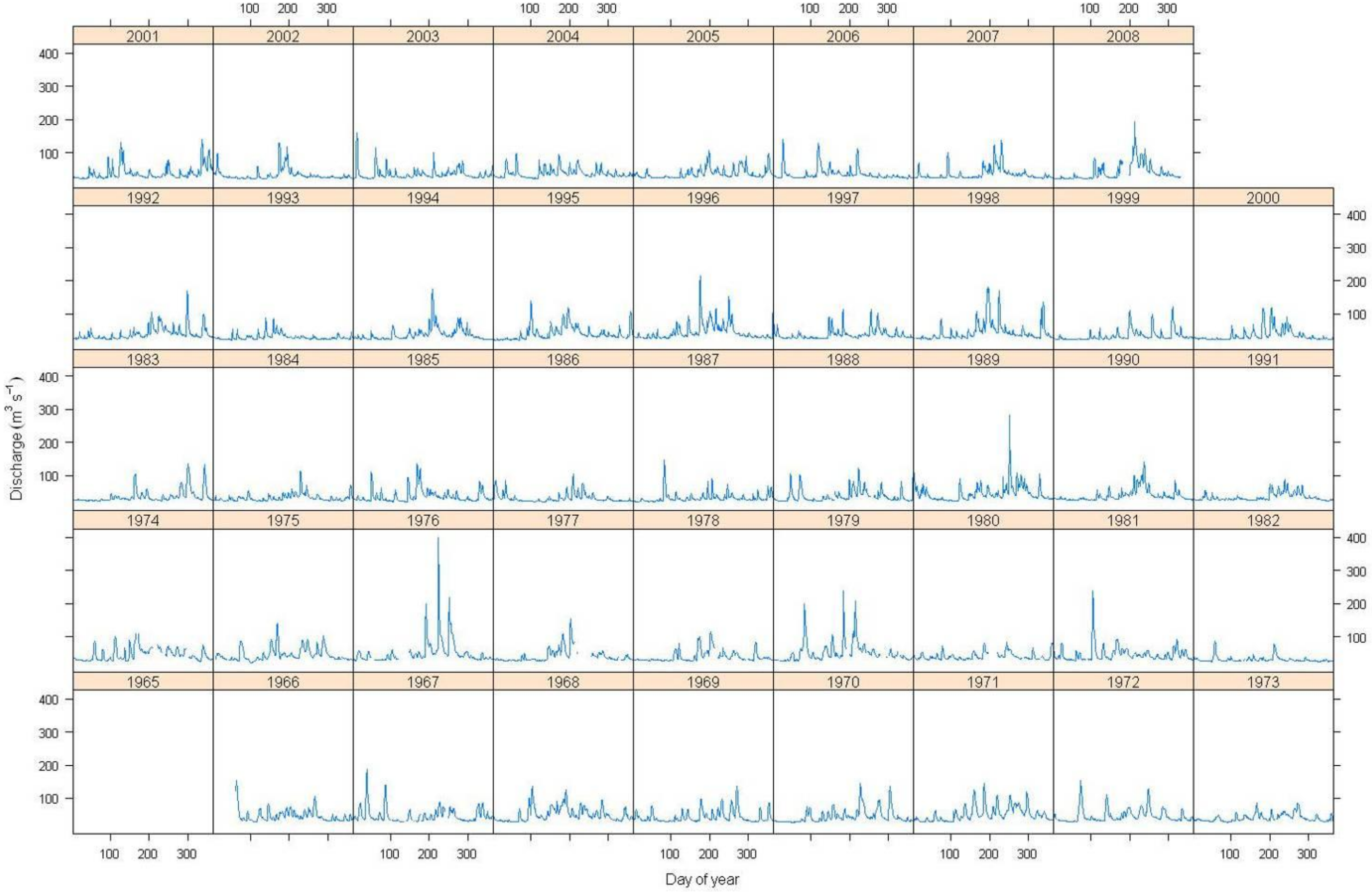

Figure 4.1: Recorded mean daily flows in the Waihou River at Tirohia.

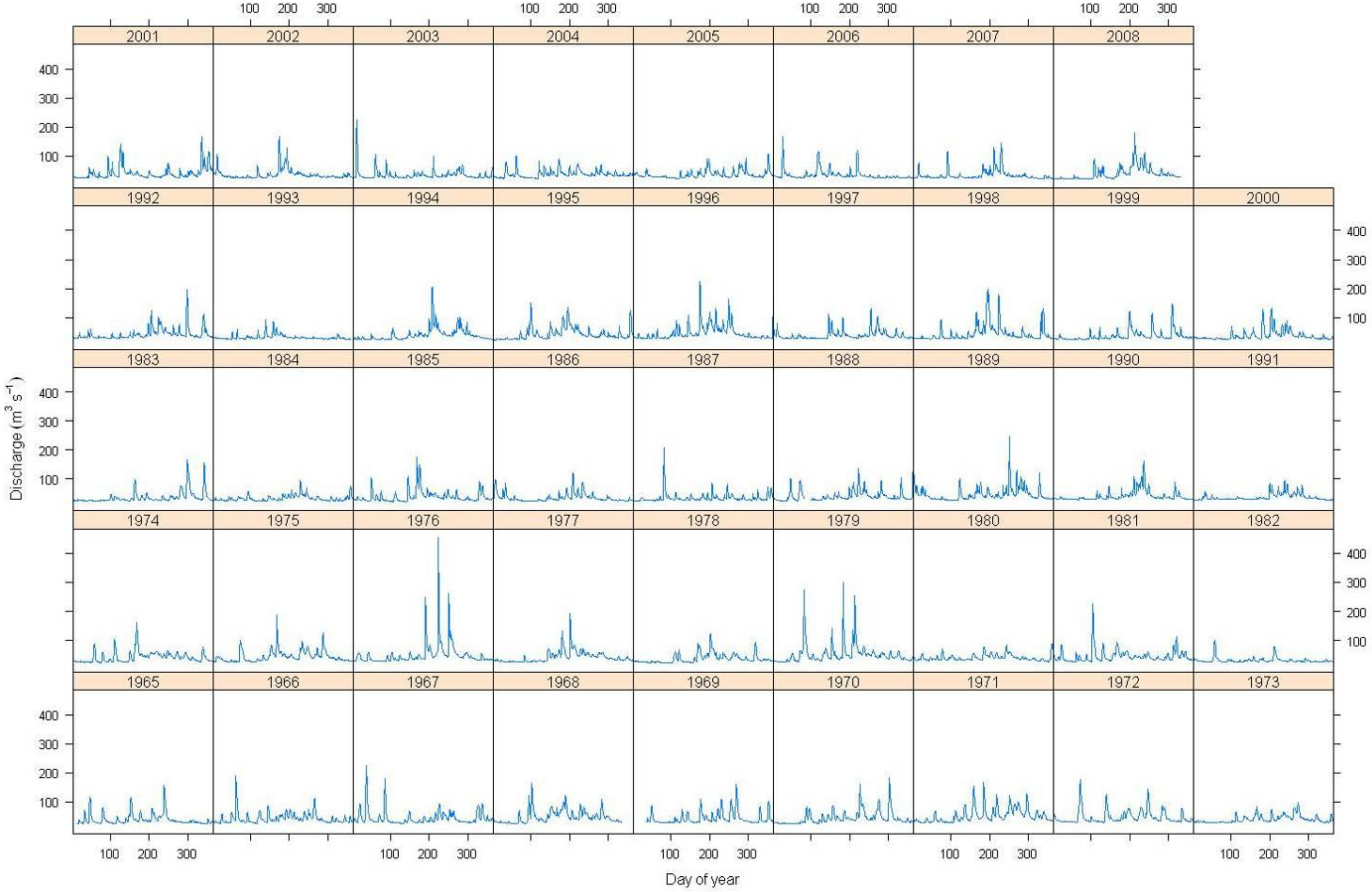

Figure 4.2: Recorded mean daily flows in the Waihou River at Te Aroha.

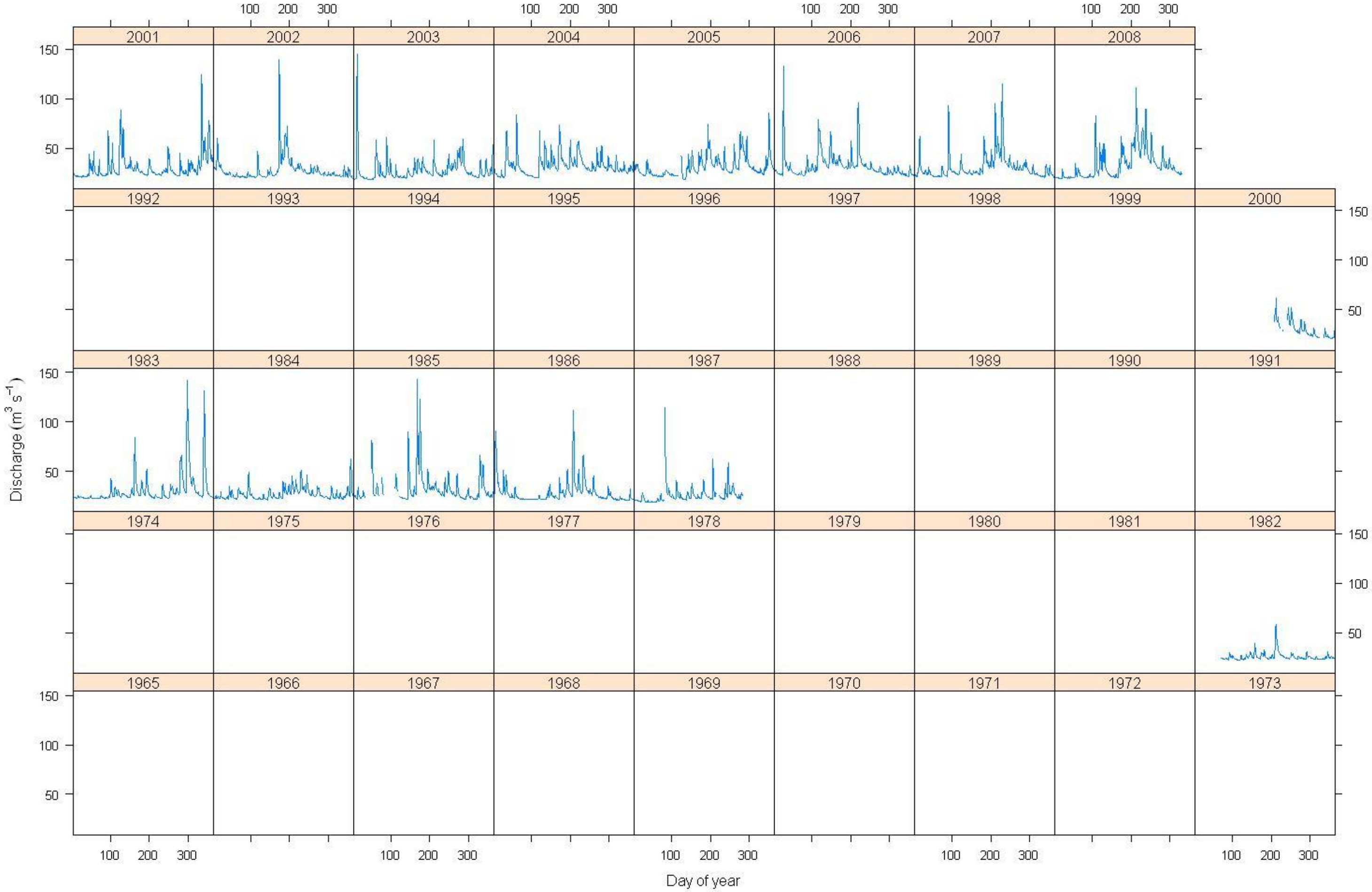

Figure 4.3: Recorded mean daily flows in the Waihou River at Shaftesbury.

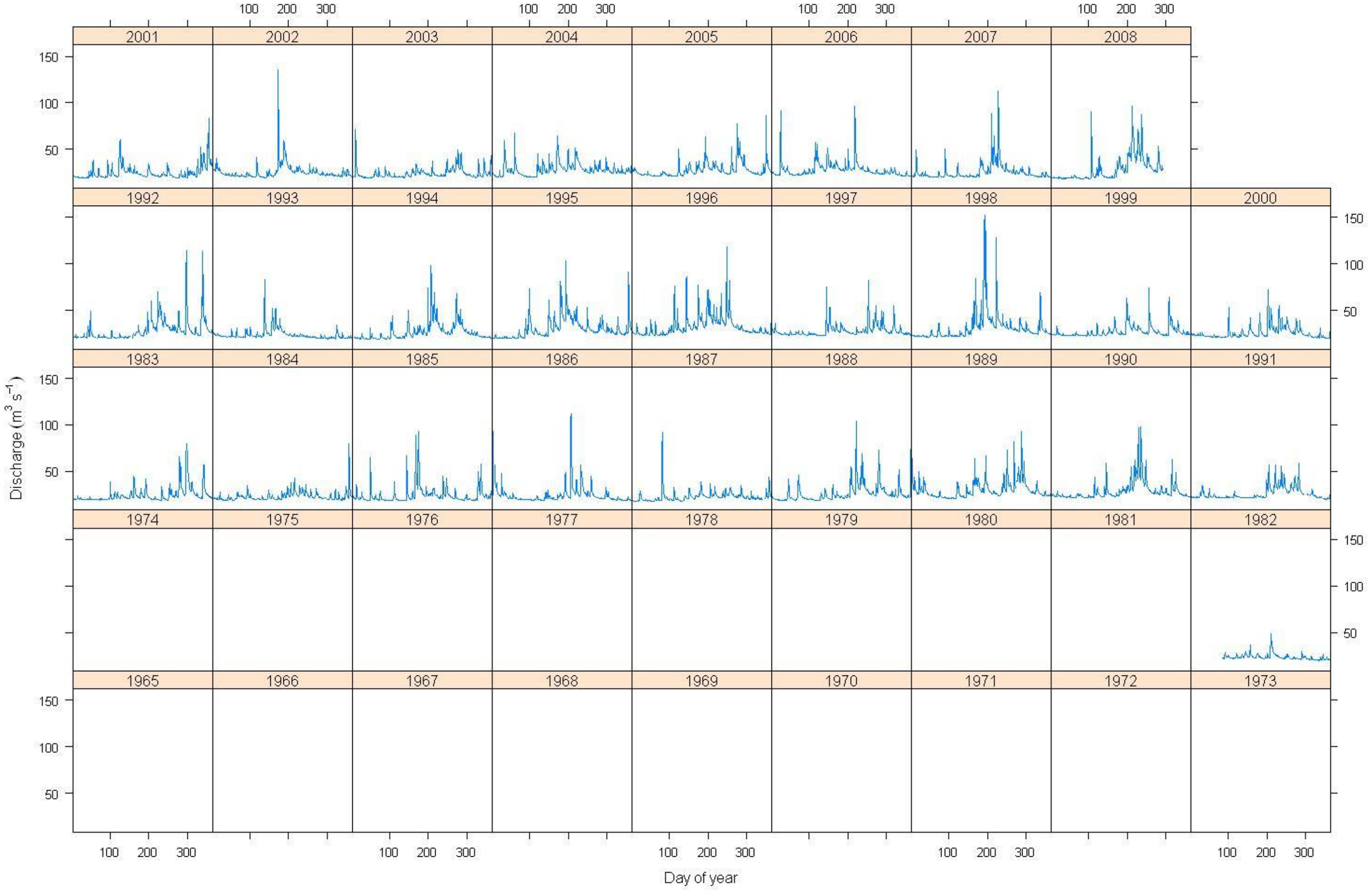

Figure 4.4: Recorded mean daily flows in the Waihou River at Okauia.

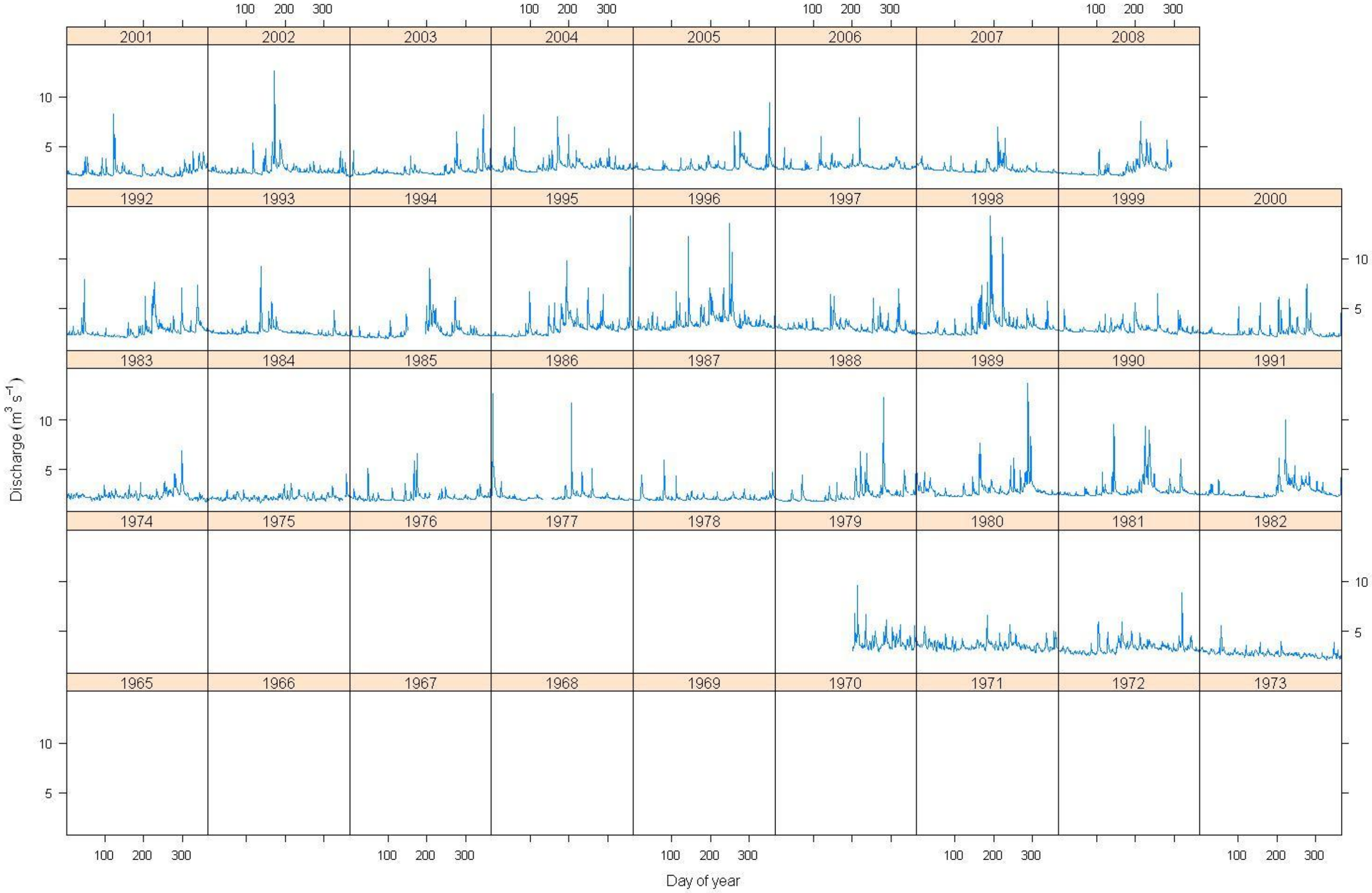

Figure 4.5: Recorded mean daily flows in the Oraka Stream at Pinedale.

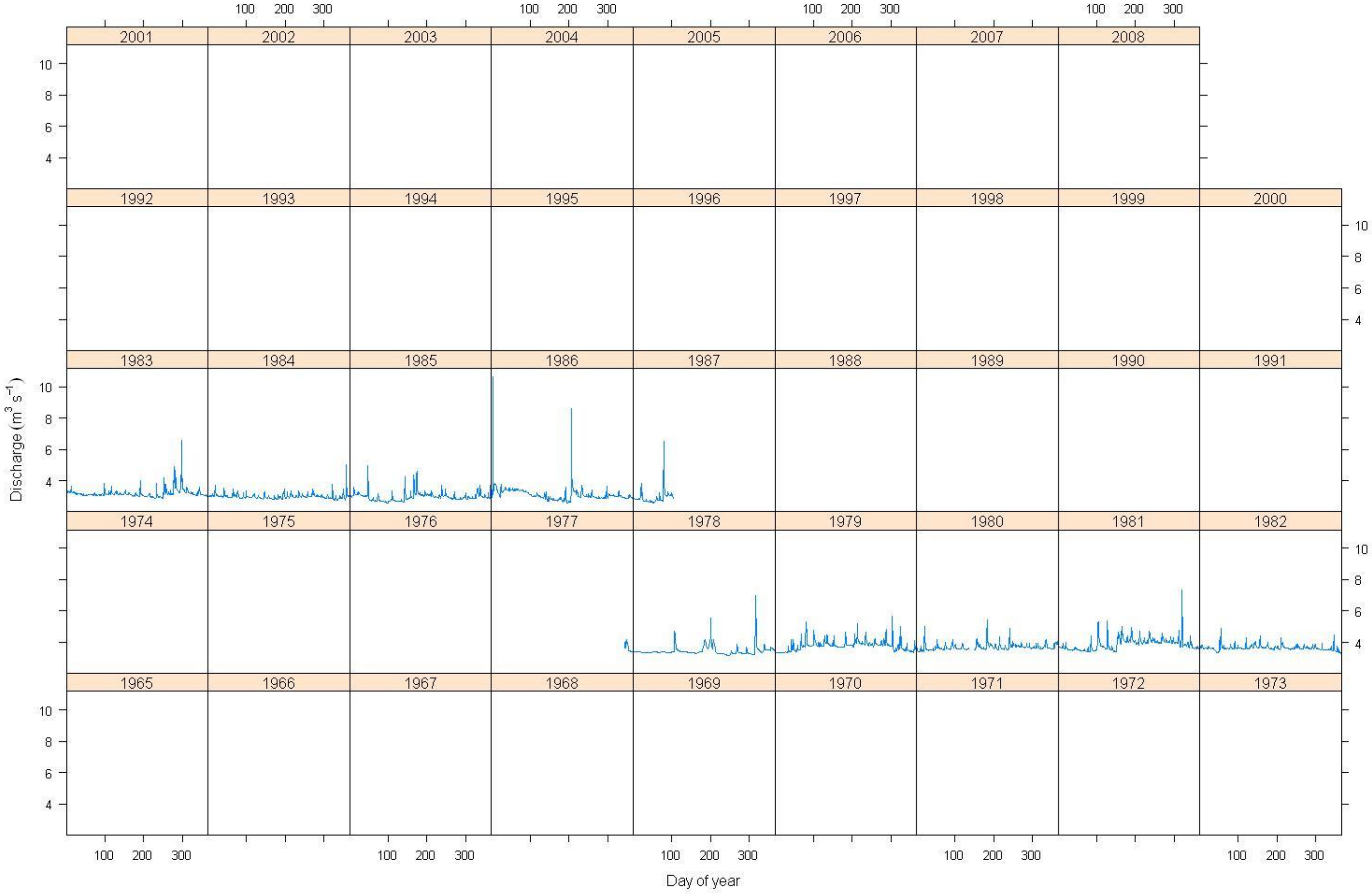

Figure 4.6: Recorded mean daily flows in the Waimakariri Stream.

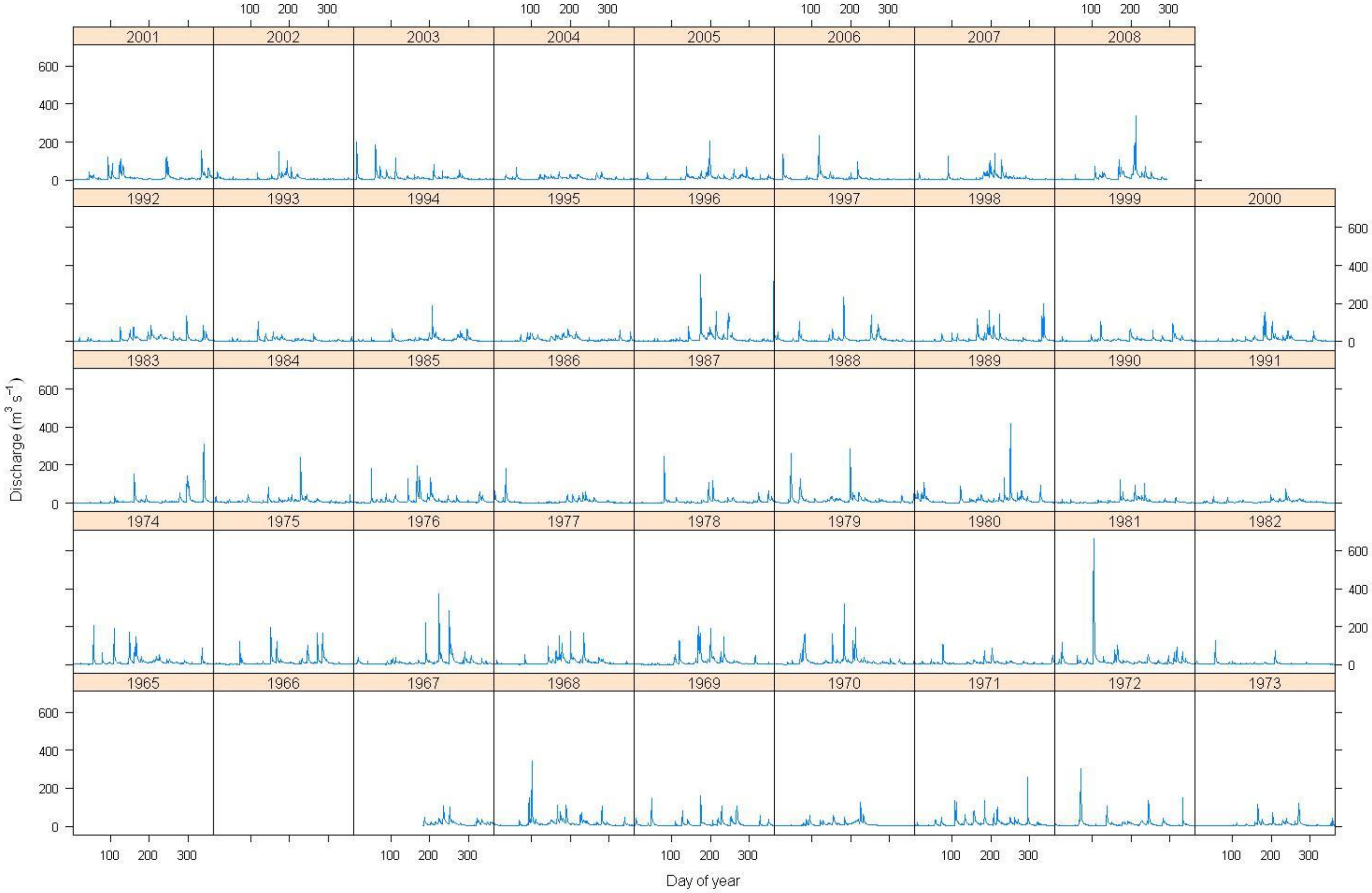

Figure 4.7: Recorded mean daily flows in the Ohinemuri River at Karangahake.

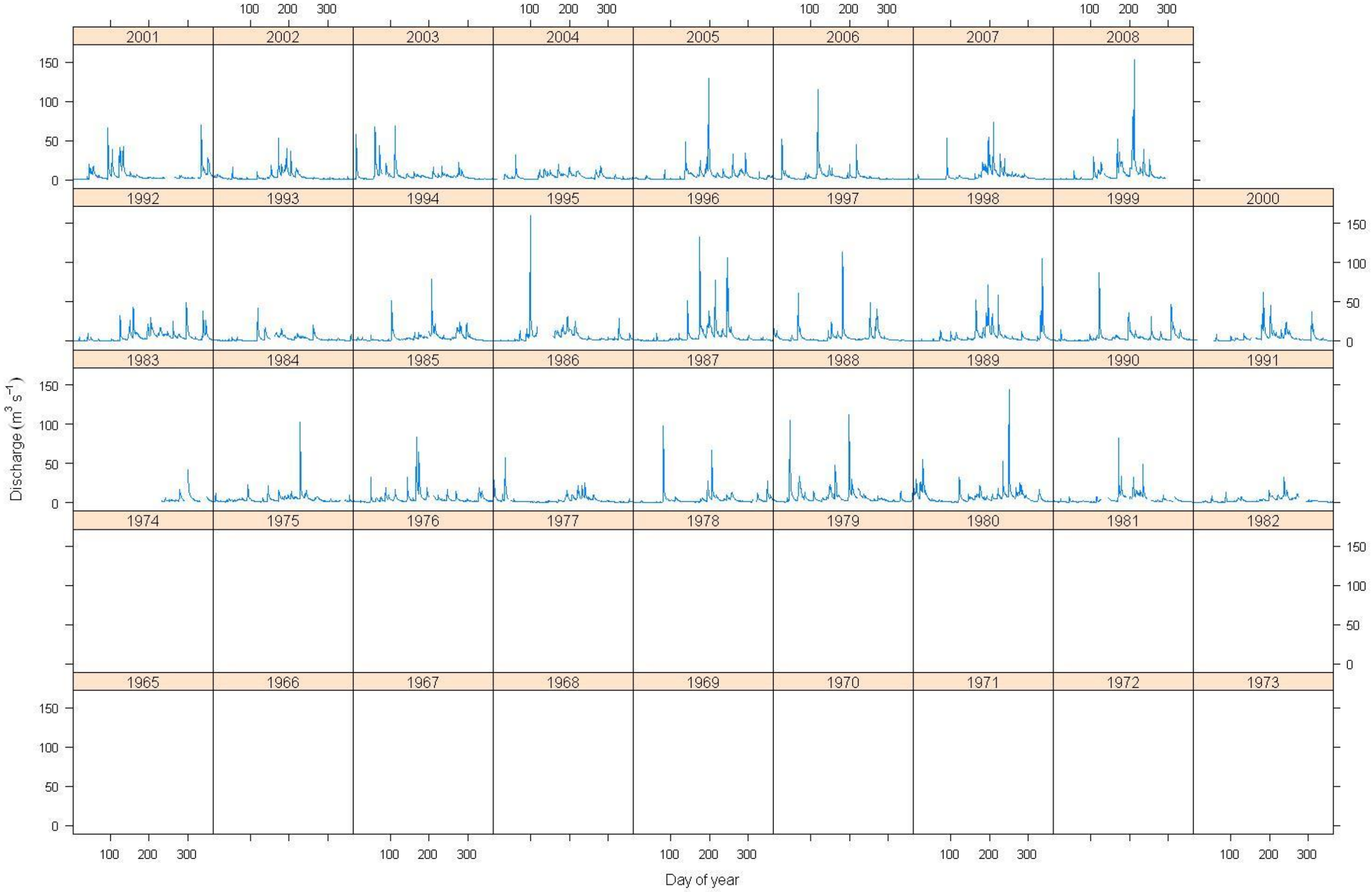

Figure 4.8: Recorded mean daily flows in the Ohinemuri River at Queens Head.

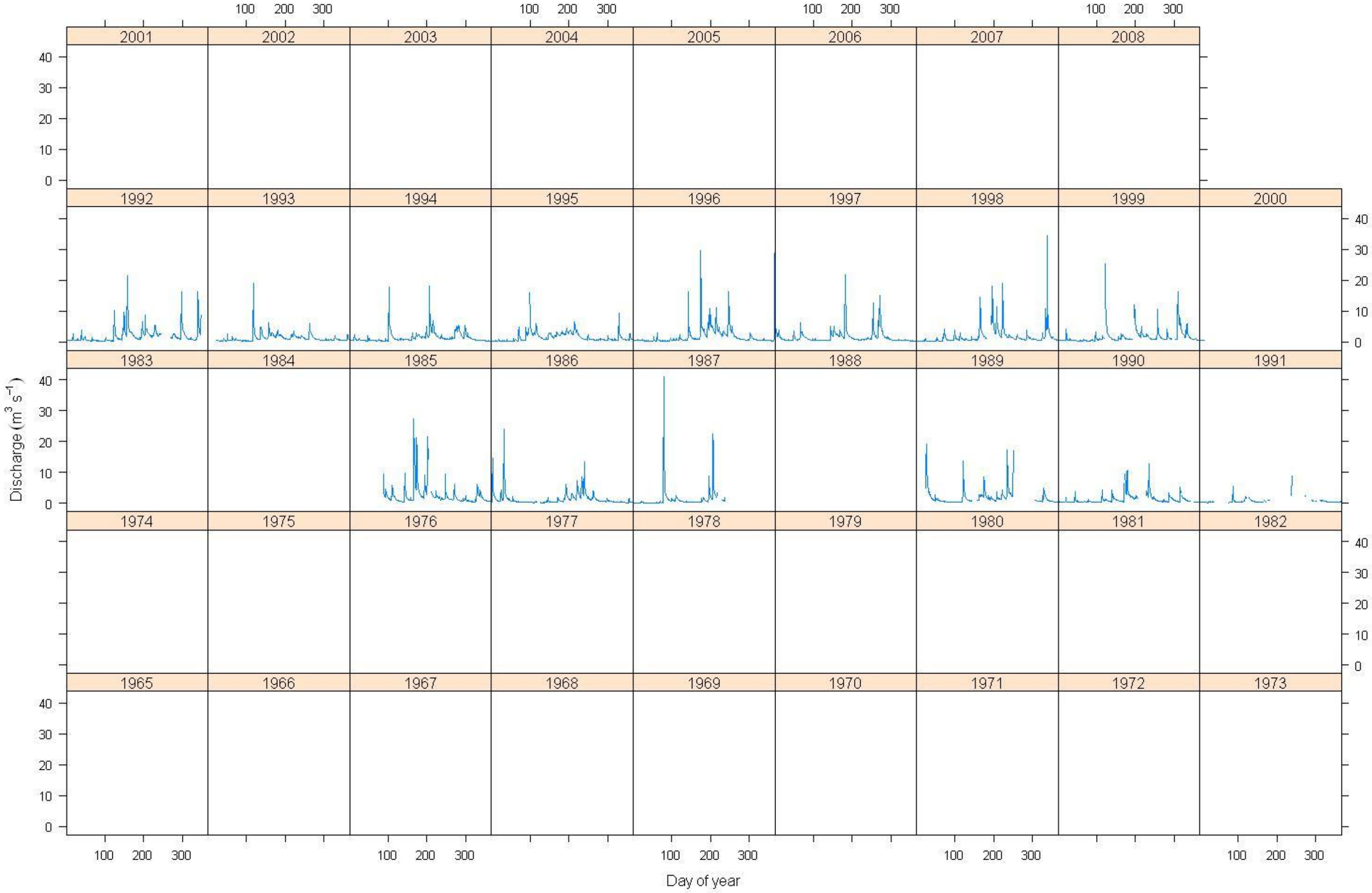

Figure 4.9: Recorded mean daily flow in the Ohinemuri River at Frendrups.

The flow regimes across the catchment are generally flashy throughout the year, and are slightly elevated over the winter period. The sites in the upper catchment appear to have a more stable flow regime consistent with a higher contribution of baseflow. Table 4.1, Figure 4.10 and Figure 4.11 provide daily flow summaries for each site. It can be seen from Figure 4.10a that in the Waihou River, the range and variance of flows generally increases with distance downstream (i.e., from Okauia to Tirohia). The inter-quartile range at Okauia is considerably narrower than at the Te Aroha and Tirohia gauging sites indicating a more stable flow regime. This is consistent with the predominance of groundwater, and hence higher baseflow contribution, in the upper catchment. This pattern is also reflected in the flow summaries for the Oraka and Waimakariri Streams.

In the lower Waihou catchment there appears to be a loss of water between the Te Aroha and Tirohia gauging sites (Table 4.1). The minimum, maximum, mean and median flows at Tirohia are all lower than that recorded at Te Aroha, despite the site being approximately 14 km downstream and receiving several small tributaries. The reason for this difference is unclear, but could be related to the flow ratings at each site or loss of water to the adjacent Piako catchment.

Flows in the Ohinemuri River are characterised by quite low medians relative to the maximums recorded at each site. The mean flow at Karangahake (12.13 $m^3 s^{-1}$) is approximately double the median flow (6.37 $m^3 s^{-1}$) suggesting relatively low base flows, but a high frequency of high flow/flooding events.

Table 4.1: Daily flow summaries for the nine sites with the longest flow records.

Site	**Daily flows (m^3s^{-1})**						**Record length**			
	Min.	1st Quartile	Median	Mean	3rd Quartile	Max.	Years	StartYear	EndYear	GapDays
Waihou River at Te Aroha	21.01	29.08	34.13	40.93	44.26	454.40	42	1966	2008	101
Waihou River at Tirohia	19.92	27.95	33.66	40.40	44.84	399.70	41	1965	2008	334
Ohinemuri River at Karangahake	1.11	3.60	6.37	12.13	12.86	663.30	40	1967	2008	30
Oraka Stream at Pinedale	1.67	2.33	2.65	2.82	3.06	14.32	28	1979	2008	128
Waihou River at Okauia	17.83	21.55	24.00	26.75	28.48	152.70	25	1982	2008	52
Ohinemuri River at Queens Head	0.32	1.37	2.66	5.13	5.71	160.60	23	1983	2008	225
Ohinemuri River at Frendrups	0.15	0.48	0.84	1.60	1.83	40.96	10	1986	1999	128
Waihou River at Shaftesbury	17.95	23.10	26.08	29.78	31.72	145.20	10	1983	2008	16
Waimakariri Stream at 273 Waimakariri Rd	2.59	3.04	3.40	3.41	3.67	10.62	9	1978	1986	15

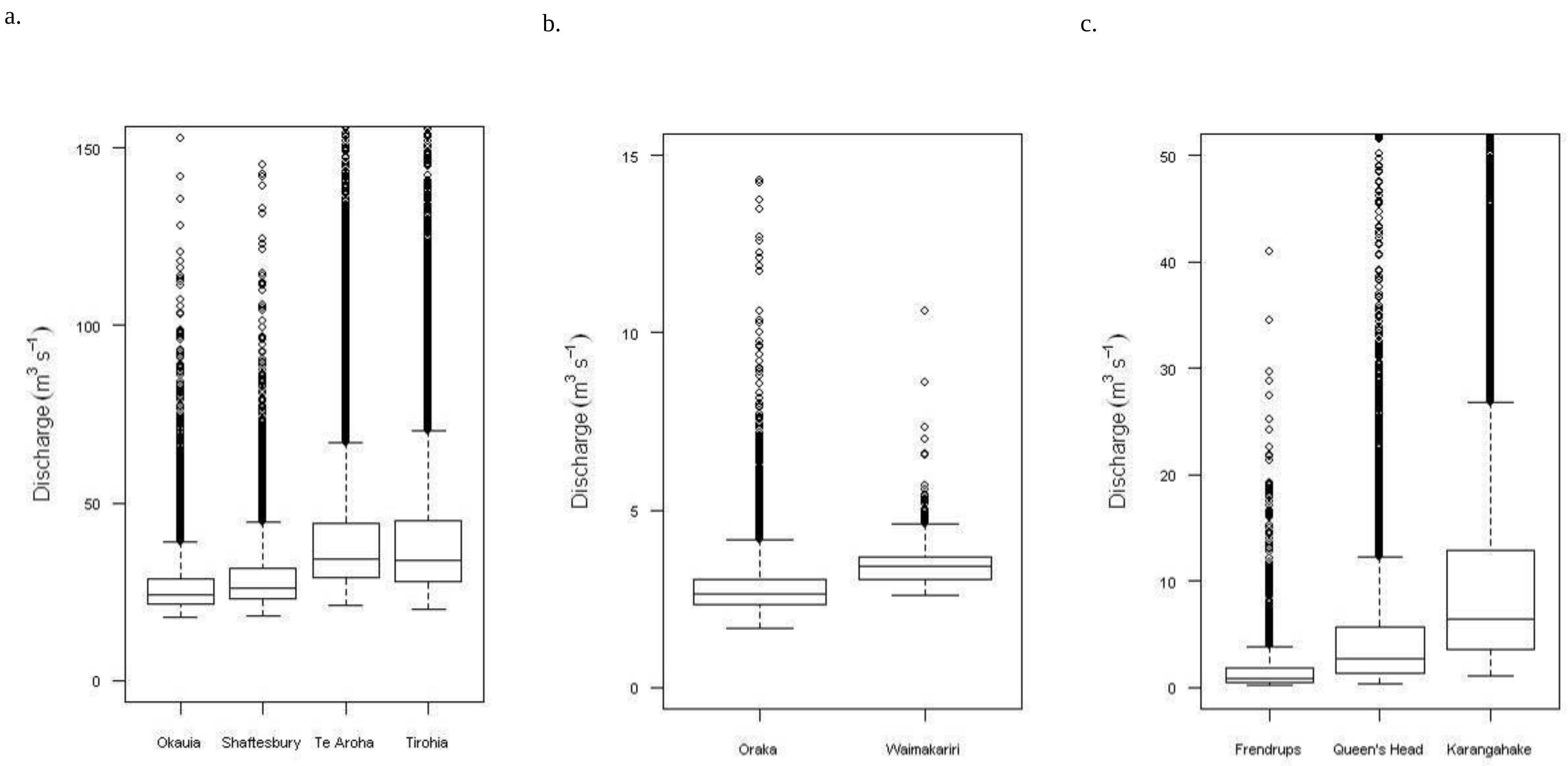

Figure 4.10: Boxplots summarising daily flows for the nine sites in the Waihou catchment with the longest flow records. a. Waihou River; b. upper Waihou catchment; c. Ohinemuri River. N.B. Boxes represent median and inter-quartile range. Whiskers extend to the most extreme data point which is no more than 1.5 times the interquartile range from the box. Data points outside this range are shown by open circles.

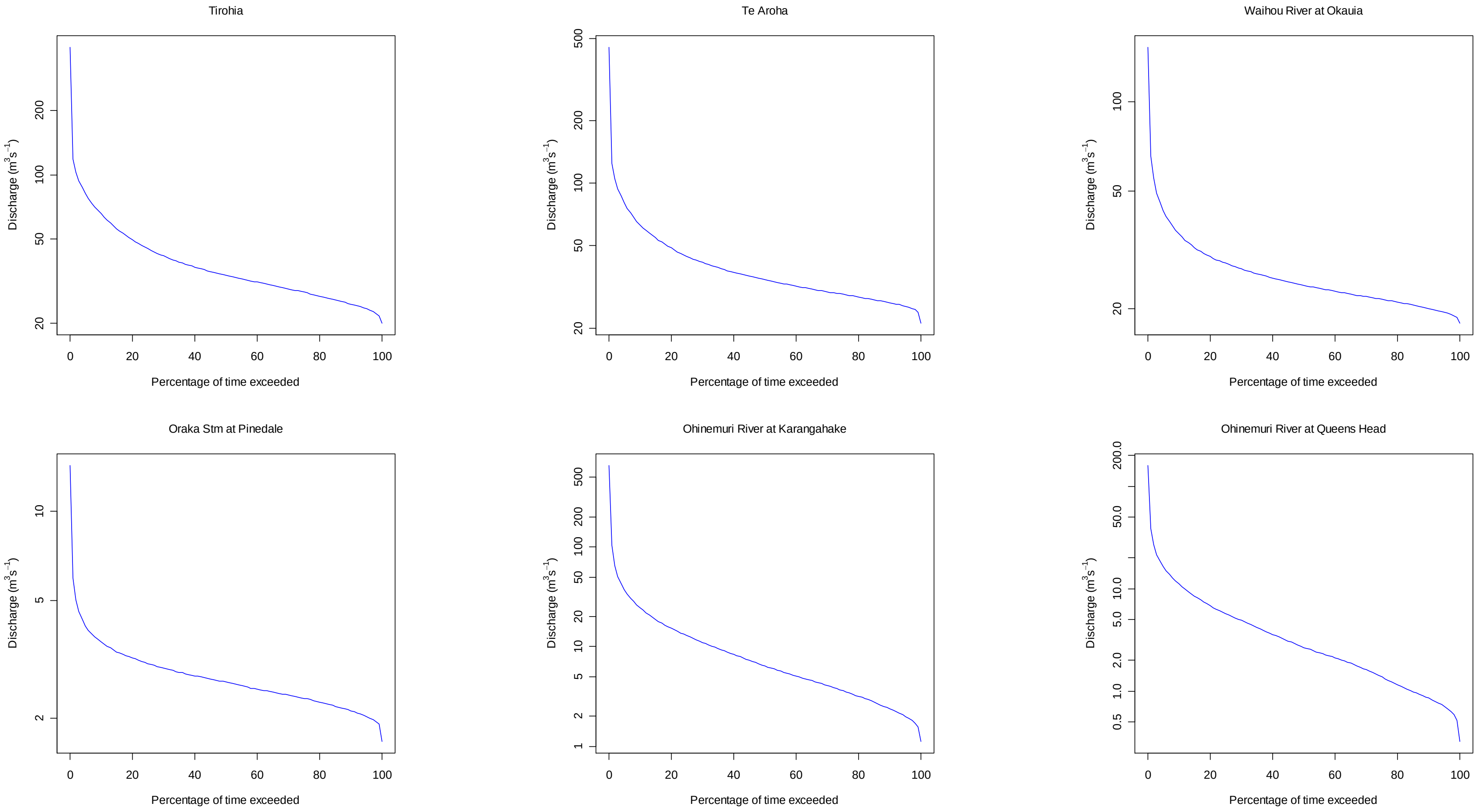

Figure 4.11: Flow duration curves for the six gauging sites in the Waihou catchment with the most complete long-term flow records.

Figure 4.12 displays the scatterplots and corresponding Pearson's correlation coefficient (r) for the nine gauging stations. The strongest correlations existed between the Te Aroha site and the Shaftesbury (r = 0.95) and Tirohia (r = 0.95) sites on the Waihou River, and between the Queen's Head site and the Karangahake (r = 0.96) and Frendrups (r = 0.94) sites on the Ohinemuri River. Extending the Frendrups and Shaftesbury records would provide little added value to the analysis due to their proximity to sites with longer measured flow records, which were already suited to the RVA analysis. This approach would also have the advantage of ignoring any temporal changes in water use (i.e., abstractions) that may have occurred at locations between sites being compared.

In the upper Waihou catchment, only the Oraka Stream has a long term flow record and therefore it was considered potentially beneficial if the Waimakariri Stream record could be successfully utilised to improve spatial coverage in this region of the catchment. Figure 4.12 shows that the best correlation (r = 0.84) for the Waimakariri Stream was with the record from the Oraka Stream at Pinedale. A linear regression between flows in the Oraka and Waimakariri Streams produced a statistically significant relationship ($p<0.001$; $r^2 = 0.71$). The regression relationship was used to create a time series of predicted flows for the Waimakariri Stream and was then compared to the available measured flows (Figure 4.13). It can be seen that whilst there is reasonable general agreement between the two time series, there are significant periods when the predicted flows are either over or under estimated, compared to the measured flows. In particular, the modelled data fails to capture the peak flows during flood events. Whilst this may be suitable for some applications, some of the hydrologic parameters calculated as part of the RVA analysis are highly sensitive to such discrepancies. Consequently, it was concluded that it was inappropriate to use a synthetic flow record for this site. In order to extend the analysis to further sites, the creation of a naturalised flow regime using a process-based, rainfall-runoff modelling approach is probably required.

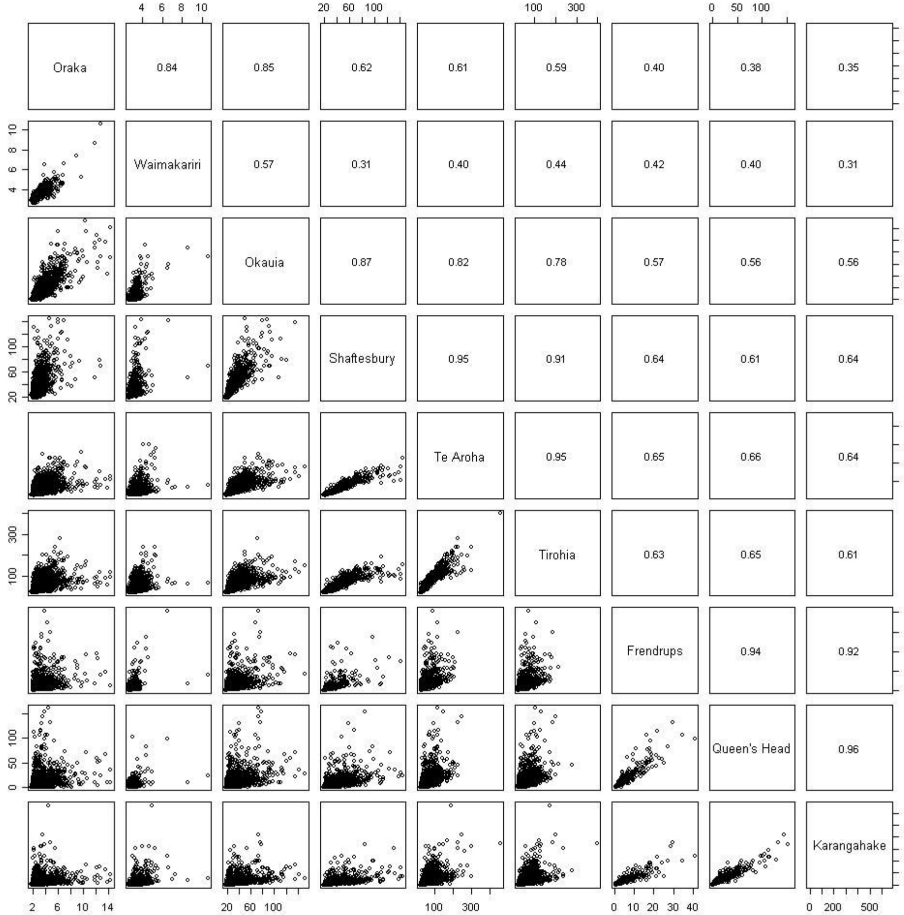

Figure 4.12: Scatterplots showing flow (m^3 s^{-1}) relationships between gauging sites. Correlation coefficients (Pearson’s r) shown in upper diagram.

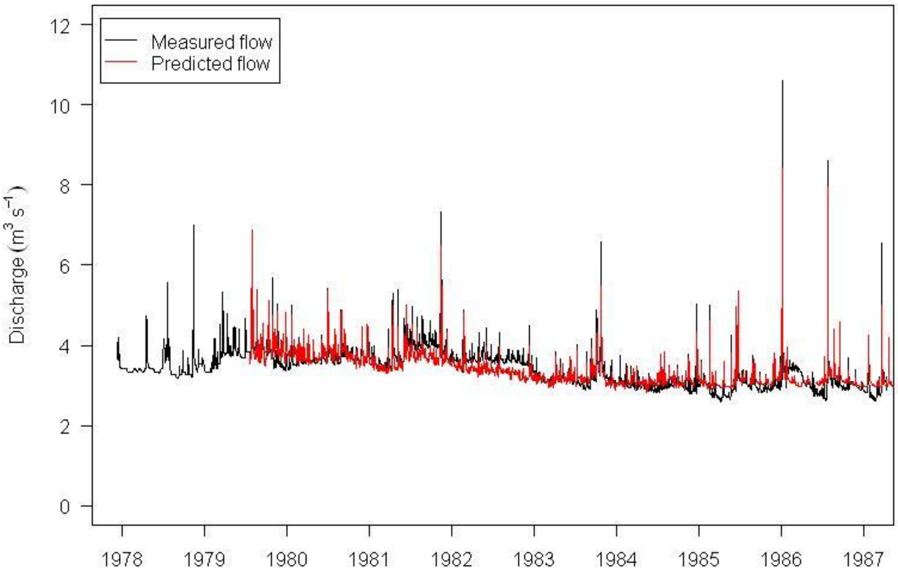

Figure 4.13: Predicted versus measured flows for the Waimakariri River based on the correlation with the Oraka Stream at Pinedale.

4.1.1 Range of variability analysis

Normality tests for parameters with within-year distributions

Shapiro-Wilk normality tests were applied to each of the within month flow distributions. P-values for Shapiro-Wilk normality tests are accepted if P-values are < 0.1 (Royston, 1995). For the vast majority of months the distribution of daily flow values at all sites were significantly different from the normal distribution. Only 5% of months from all sites met the P-value < 0.1 criterion. This suggests that the within month flows cannot be assumed to have normal distributions in the majority of cases. Therefore, using the median of the daily values for each month provides the best measure of the seasonal patterns in flow because median values describe the central tendency of the flows for any given month.

For the remaining parameters that have within-year distributions, normality of the within-year distributions were also assessed using p-values on Shapiro-Wilk tests. The majority of within-year distributions were not normal, including: the duration of each low pulse within each year; the duration of each high pulse within each year; the positive differences between daily values; and the negative differences between daily values. This suggests that the mean values for these parameters are not good representations of central tendency. A higher proportion of normal distributions were found for the duration of each high pulse within each year. This suggests that, at certain sites, the mean value may be an adequate representation of central tendency. Due to evidence of non-normality, median, rather than mean, values for these parameters were used in subsequent analyses.

Temporal trends

Significant temporal trends were present for many parameters at several sites (Table 4.2). Records from the Waihou River at Tirohia (Figure 4.14) and Te Aroha (Figure 4.15) and from the Waimakariri Stream (Figure 4.19) all had significant temporal trends for many (16-20) of the parameters. This was particularly the case for parameters describing low flow conditions, such as monthly medians and flow minima (Table 4.2). Negative values in the slopes describing these trends indicate a reduction in values over time. For example, over the 42 year record on the Waihou River at Tirohia, September median flow has reduced, on average, by 0.6 $m^3 s^{-1}$ each year (Figure 4.14). By contrast, the records from the Oraka Stream and Ohinemuri River showed temporal trends in very few (1-4) of the parameters tested (Table 4.2).

The negative trends identified in the flows of the Waimakariri Stream may be a result of the relatively short flow record, which encompasses a natural transition from a wetter to a drier period, also observable in the Oraka Stream record. This highlights the importance of record length in calculating and interpreting hydrologic parameters. For the other sites where long term declines in flow have been identified, it is suggested that they are more likely a consequence of anthropogenic influences rather than natural climatic variability because such declines have not been observed throughout the catchment. The Te Aroha and Tirohia sites, where the main declines have been observed, are located in the lower part of the Waihou catchment, but upstream of the Ohinemuri River confluence. Anthropogenic impacts that may have contributed to reduced flows include increases in surface and groundwater abstraction, changes in land use and alterations in land drainage. It could also reflect changes in the flow rating curves used at each site. The reach between the Okauia gauging station and Te Aroha is currently subject to a consented maximum daily take of 47,905 $m^3 d^{-1}$ and the reach between Te Aroha and Tirohia to 21,825 $m^3 d^{-1}$. However, knowledge of historical abstraction pressure, particularly prior to 1990, is limited and thus it is difficult to know how abstraction pressure has changed.

The presence of statistically significant temporal trends negates valid application of the RVA approach. This is partly because calculation of central tendency and spread assumes untrended data, but is especially the case where the causes of these trends are anthropological. In these cases naturalised flow scenarios (i.e., one with abstractions or diversions added back to the historical flows) are required for valid application of the range of variability approach.

Table 4.2: Significant ($p<0.05$) linear temporal trends for records longer than 10 years. Values indicate slope of the relationship with time in years. Blanks indicate no significant trends.

	Oraka Stream at Pinedale: 28 years	Waimakariri Stream at 273 Waimakariri Rd: 9 years	Waihou River at Okauia: 25 years	Waihou River at Shaftesbury: 10 years	Waihou River at Te Aroha: 42 years	Waihou River at Tirohia: 41 years	Ohinemuri River at Frendrups: 10 years	Ohinemuri River at Queens Head: 23 years	Ohinemuri River at Karangahake: 40 years
Median flow ($m^3 s^{-1}$), Jan						-0.22			
Median flow ($m^3 s^{-1}$), Feb			0.12			-0.19	-0.07		
Median flow ($m^3 s^{-1}$), Mar					-0.16	-0.34			
Median flow ($m^3 s^{-1}$), Apr		-0.11				-0.29			
Median flow ($m^3 s^{-1}$), May		-0.11	0.23			-0.23		0.13	
Median flow ($m^3 s^{-1}$), Jun					-0.24	-0.38			-0.17
Median flow ($m^3 s^{-1}$), Jul		-0.16							
Median flow ($m^3 s^{-1}$), Aug					-0.32	-0.46			
Median flow ($m^3 s^{-1}$), Sep		-0.10			-0.50	-0.61			-0.12
Median flow ($m^3 s^{-1}$), Oct		-0.11							
Median flow ($m^3 s^{-1}$), Nov		-0.09			-0.16	-0.25			
Median flow ($m^3 s^{-1}$), Dec		-0.10							
1 Day Flow Mins		-0.10			-0.05	-0.18			
1 Day Flow Maxs									
3 Day Flow Mins		-0.10	0.08		-0.06	-0.18			
3 Day Flow Maxs							0.62		
7 Day Flow Mins		-0.10			-0.06	-0.19			
7 Day Flow Maxs							0.32		
30 Day Flow Mins		-0.09	0.08		-0.06	-0.21			
30 Day Flow Maxs		-0.09							
90 Day Flow Mins		-0.09	0.10		-0.10	-0.27			
90 Day Flow Maxs					-0.25	-0.38			
Zero Flow Days									
Base Flow Index				0.00					
Julian day of min. flow									

	Oraka Stream at Pinedale: 28 years	Waimakariri Stream at 273 Waimakariri Rd: 9 years	Waihou River at Okauia: 25 years	Waihou River at Shaftesbury: 10 years	Waihou River at Te Aroha: 42 years	Waihou River at Tirohia: 41 years	Ohinemuri River at Frendrups: 10 years	Ohinemuri River at Queens Head: 23 years	Ohinemuri River at Karangahake: 40 years
Julian day of max. flow									
Number of low pulses		3.67			0.21	0.31			
Median duration low pulses		-59.9				-7.41			
Number of high pulses	0.41								
Median duration high pulses		-0.28			-0.12	-0.11			
Number of positive differences between days	-1.08	6.63							
Median of positive differences between days									
Number of negative differences between days	1.27	5.60			0.54	0.64			
Median of negative differences between days	0.00				0.01				
Reversals					0.85	0.39			0.62

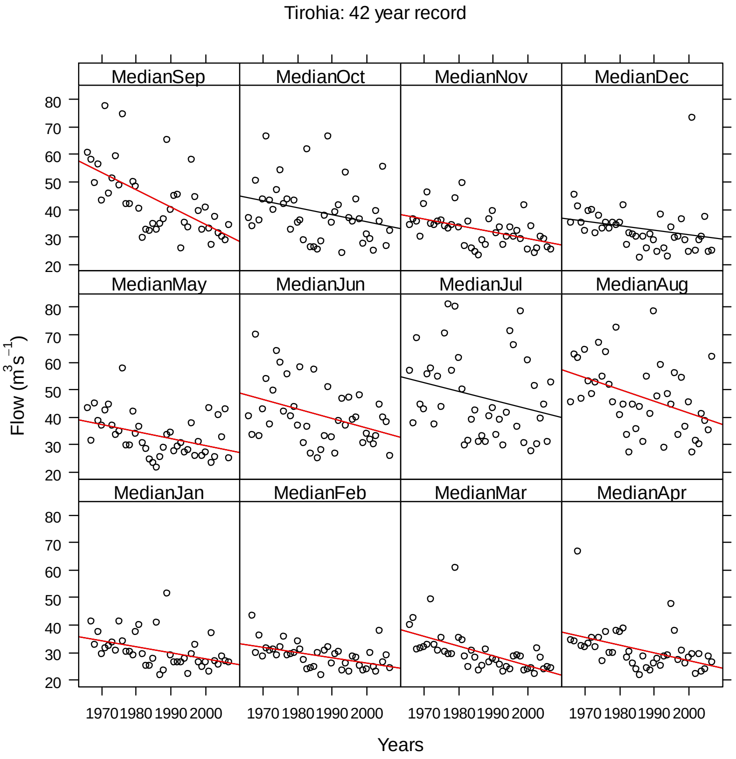

Figure 4.14: Temporal trends in monthly median recorded flows in the Waihou River at Tirohia. Red trend lines indicate a statistically significant result ($p<0.05$).

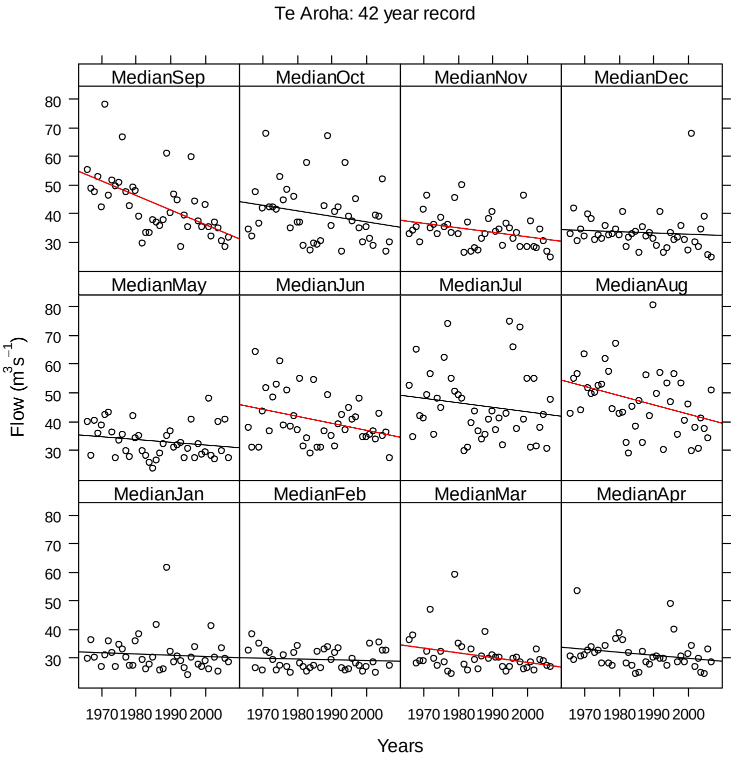

Figure 4.15: Temporal trends in monthly median recorded flows in the Waihou River at Te Aroha. Red trend lines indicate a statistically significant result (p<0.05).

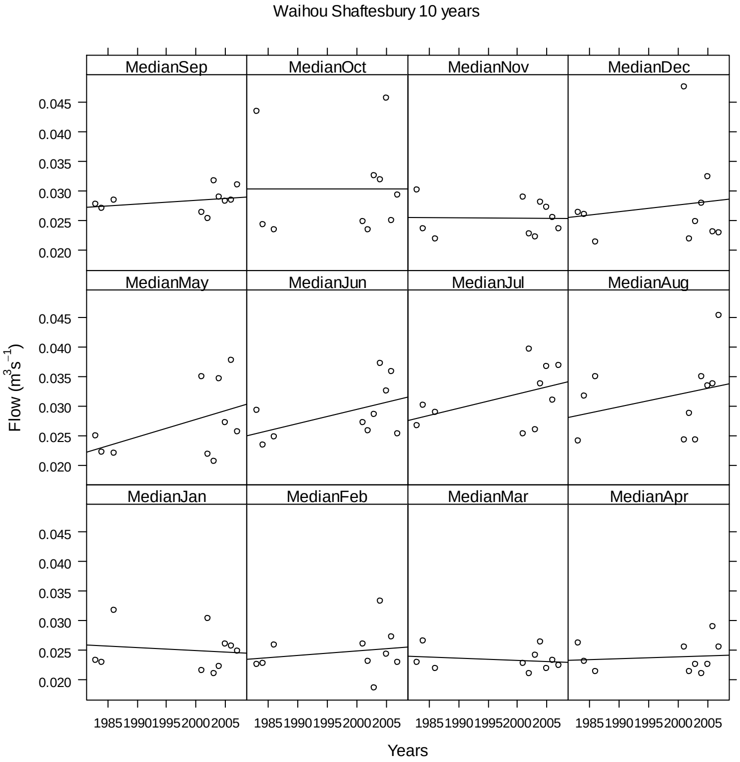

Figure 4.16: Temporal trends in monthly median recorded flows in the Waihou River at Shaftesbury. Red trend lines indicate a statistically significant result (p<0.05).

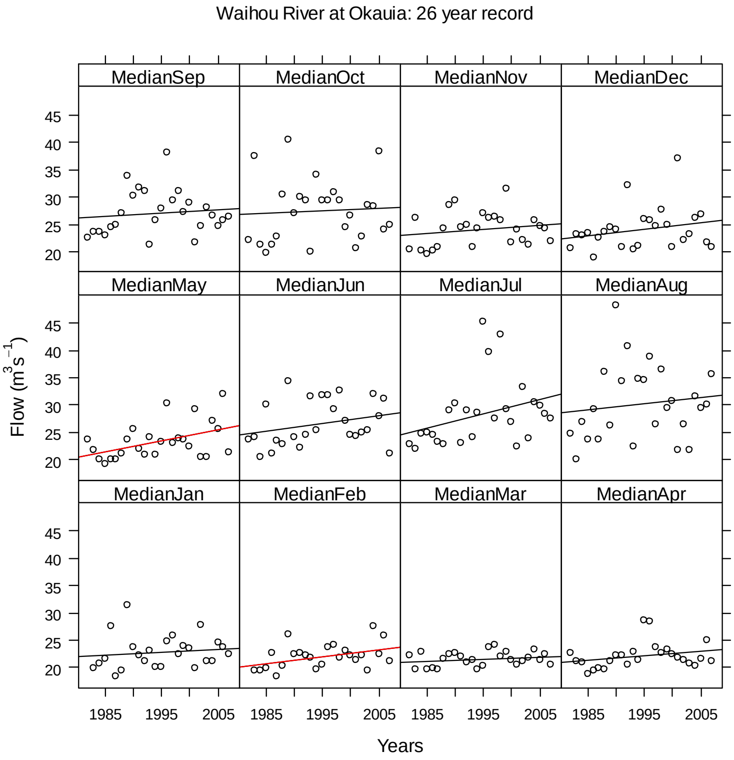

Figure 4.17: Temporal trends in monthly median recorded flows in the Waihou River at Okauia. Red trend lines indicate a statistically significant result (p<0.05).

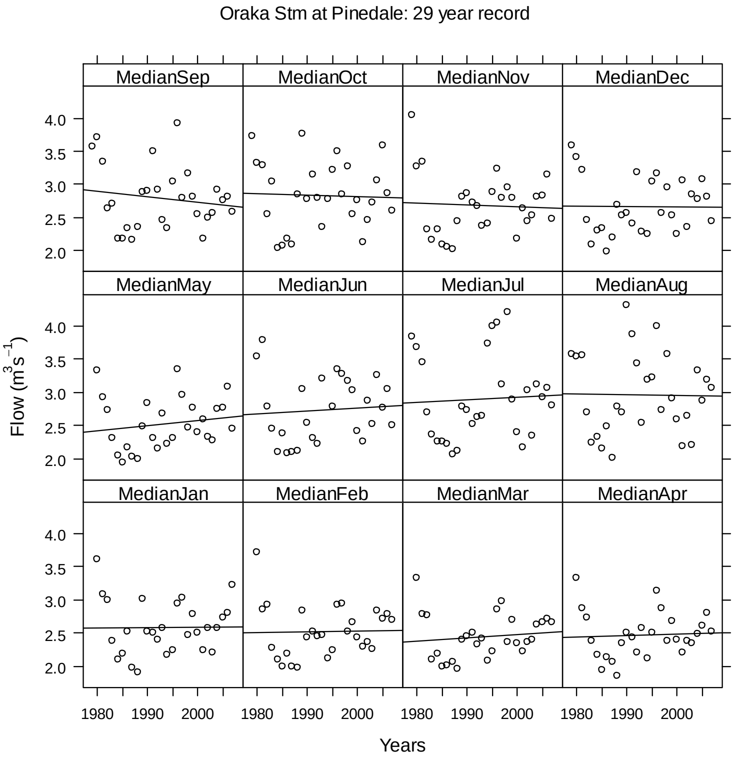

Figure 4.18: Temporal trends in monthly median recorded flows in the Oraka Stream at Pinedale. Red trend lines indicate a statistically significant result (p<0.05).

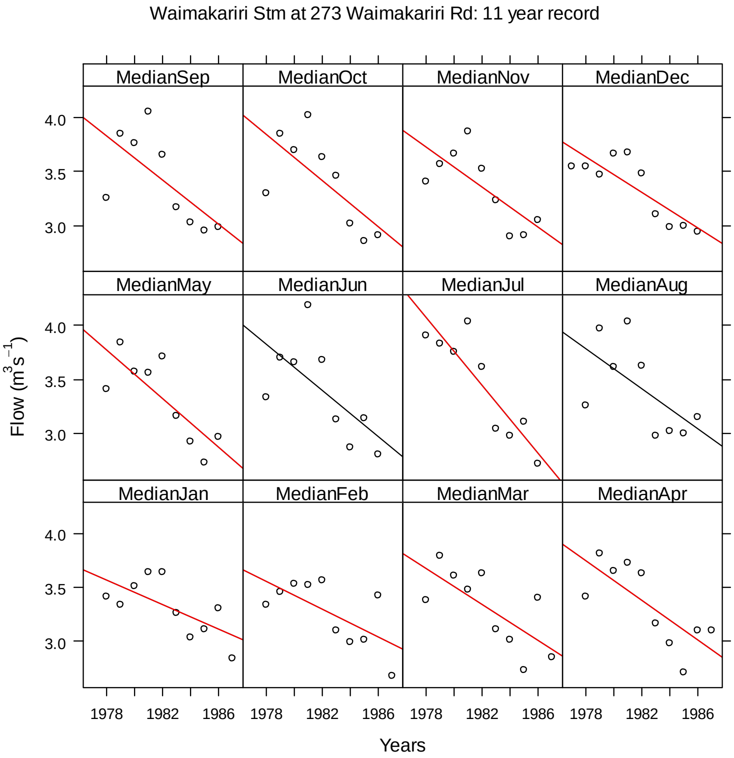

Figure 4.19: Temporal trends in monthly median recorded flows in the Waimakariri Stream. Red trend lines indicate a statistically significant result ($p<0.05$).

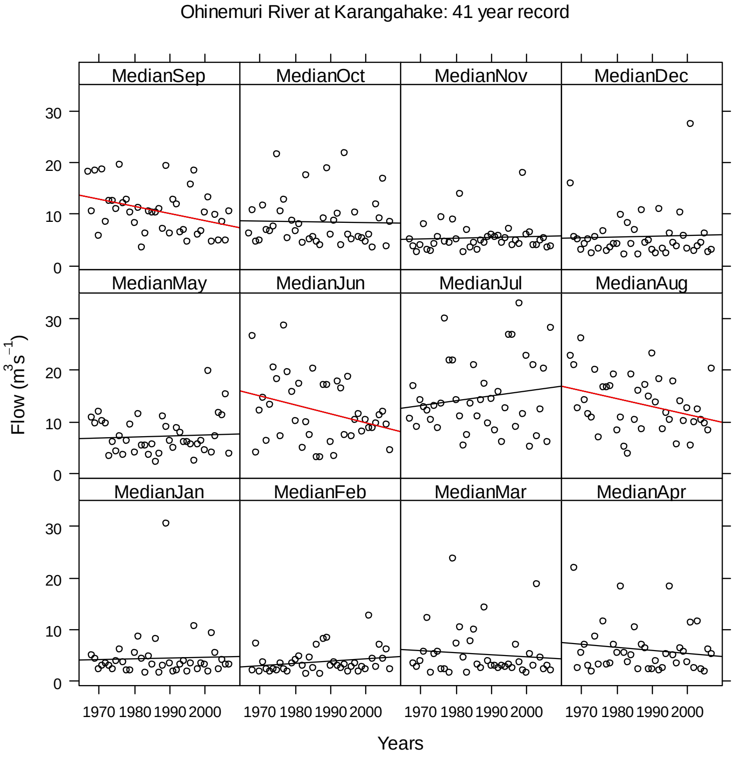

Figure 4.20: Temporal trends in monthly median recorded flows in the Ohinemuri River at Karangahake. Red trend lines indicate a statistically significant result ($p<0.05$).

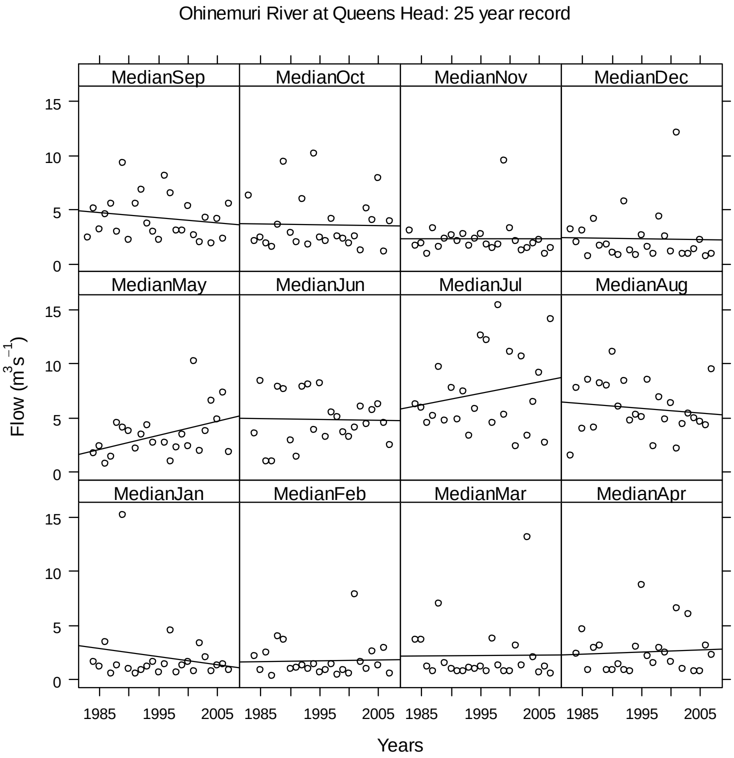

Figure 4.21: Temporal trends in monthly median recorded flows in the Ohinemuri River at Queens Head. Red trend lines indicate a statistically significant result (p<0.05).

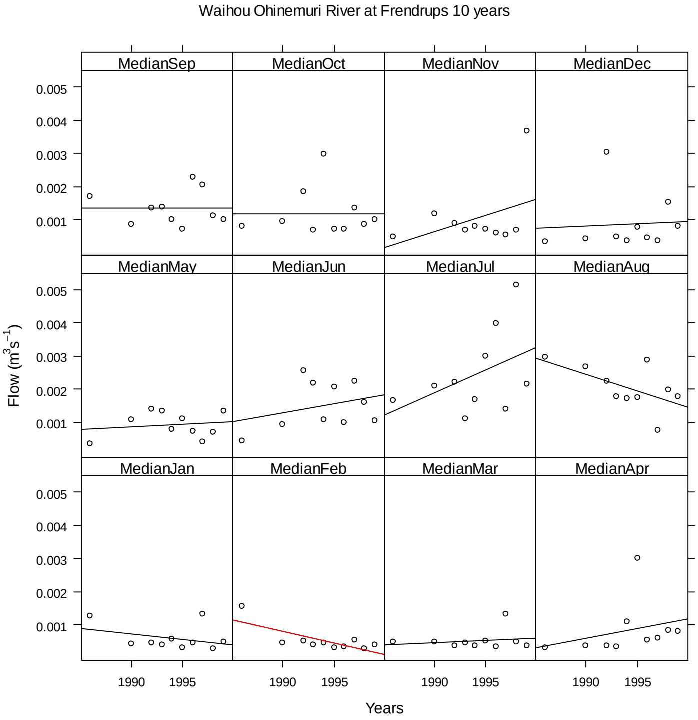

Figure 4.22: Temporal trends in monthly median recorded flows in the Ohinemuri River at Frendrups. Red trend lines indicate a statistically significant result (p<0.05).

Autocorrelation

Tests for serial dependence were not carried out for all sites, since many of the variables from the sites with longer records showed evidence of significant temporal trends and heteroscedasticity (changes in variance through time). However, as only three of the 35 parameters calculated for the Ohinemuri River at Karangahake showed statistically significant temporal trends, data from this site were tested for serial dependence to demonstrate the methods used, and to assess the length of record required to apply the RVA at this site. Of the 35 annual hydrological parameters for this site, only 7 had statistically significant partial autocorrelations (Table 4.3). Positive autocorrelations occur when similar values are found consistently at the same lags (number of years apart). For example, a 1 year positive autocorrelation for the number of reversals suggests that the number of reversals in any given year is likely to be similar to the number of reversals one year ago (Figure 4.23). The presence of only short lags indicates a lack of serial dependence within the record for the analysed parameters over the length of the observed data. This suggests that, for this site, there is no evidence of cyclical trends in time, except at relatively short lags, for the analysed variables. A lack of cyclical trends at the > 10 year time-scale implies that the data are stationary and that serial dependence does not have to be considered when determining the minimum record length required to capture the range of natural variability.

Table 4.3: Partial autocorrelations above the 95% confidence limits for all 35 parameters calculated for the Ohinemuri River at Karangahake.

Parameter	Lag (years) and direction of partial autocorrelation
3 Day Flow Max	10 year negative
7 Day Flow Min	2 year negative
30 Day Flow Mins	2 year negative
90 Day Flow Mins	2 year negative
Julian day of min flow	6 year negative
Number of high pulses	2 year negative
Reversals	1 year positive

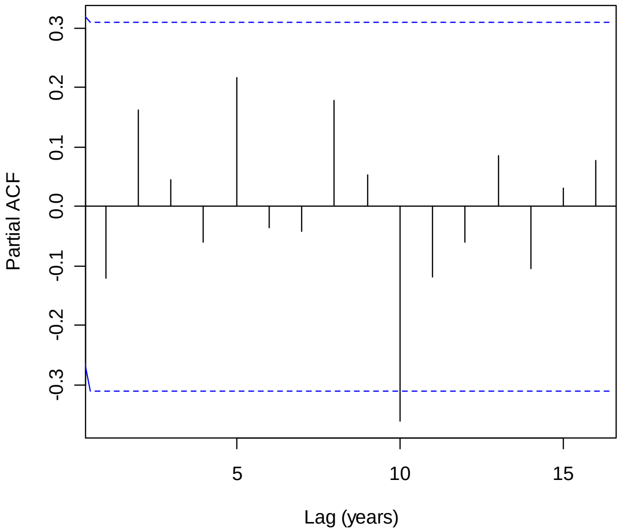

Figure 4.23: Partial autocorrelation for the 3 day flow maxima for the Ohinemuri River at Karangahake. Dashed lines indicate 95% confidence limits. Vertical lines indicate magnitude of autocorrelation.

Characterising flow variability using RVA

The RVA is designed to compare pre- and post- impact flow scenarios (The Nature Conservancy, 2007). These were not available in this project. However, the range of variability for the measured records can still be quantified using the hydrologic parameters in Table 3.2. The following section summarises the distributions of different flow components for each of the sites with sufficiently long flow records. These reflect the five key components of the flow regime: magnitude, frequency, duration, timing and rate of change in flows. For the Waihou River at Te Aroha and Tirohia, where many of the parameters showed significant temporal trends, the range of variability is not very informative. This is because the trends will be captured within the measures of variability. The results are, however, presented for comparison.

Ohinemuri River at Karangahake

Table 4.4 summarises the hydrologic parameters calculated for the flow record from the Ohinemuri River at Karangahake. Each parameter represents a different component and characteristic of the flow regime. The 33rd and 66th percentiles indicate the boundary of variation for which, on average, three in every ten years should be within. The 16th and 84th percentiles represent the range of natural variability for which, on average, six in every ten years should fall within. The distributions of some of the key parameters that can be used for informing flow management decisions are illustrated in Figure 4.24 to Figure 4.31. The kernel density curves can be interpreted as a probability function for each parameter, reflecting the distribution of the measured data (plotted as open circles above the x-axis).

Figure 4.24 compares the median monthly flows for the Ohinemuri River at Karangahake. A distinct seasonal pattern is apparent with the summer period (Nov-Mar) being characterised by a relatively narrow range of flows compared to the wide range experienced over the winter months, and transitional periods in autumn and spring. This can be interpreted to represent relatively stable low flows during summer followed by high levels of rainfall-driven flow variability in winter. The lowest median of the monthly flows is experienced in February and is 22% of the highest median of the monthly flows which occurs in July.

The mean 7-day low flow statistic (Figure 4.25) is frequently used as a guide for low flow analysis. The median value is 1.94 $m^3 s^{-1}$ (Table 4.4) and, on average, for 1 in every 3 years (i.e., between the 33rd and 66th percentiles) the mean 7-day low flow will be within ±8% of this flow, indicating a relatively high level of inter-annual consistency in the low flow conditions (Table 4.4). Figure 4.26 shows the distribution of the five other low flow statistics, also illustrating the relatively consistency of low flows between years.

Figure 4.27 shows the distribution of the high flow statistics for the Ohinemuri River at Karangahake. A log scale is used on the x-axis to account for the order of magnitude variation in range for the shorter duration (1, 3 and 7-day flow maxima) events. As would be expected, the variability in peak flow narrows with increasing event duration as the influence of extreme events is reduced. The median 1-day maximum flow is 196.4 m^3 s^{-1} and on average for every 1 in 3 years the maximum flow will be within approximately ±20% of the median. A similar level of variability is displayed in the 7-day flow maxima, with, on average, 1 in 3 years falling within approximately ±17% of the median of 70.22 m^3 s^{-1} (Table 4.4). This indicates that there is considerably higher variability between years in the shorter duration high flow events when compared to the equivalent duration low flow events.

The base flow index (BFI) represents the average portion of stream flow that comes from baseflow as compared to runoff. It is calculated as the 7-day minimum flow divided by mean flow for the year. The BFI ranges from 0 to 1 with 1 meaning 100% contribution from baseflow. It can therefore be used as an indicator of the relative 'flashiness' of the flow regime. Figure 4.28 shows the distribution of BFI over the duration of the flow record. The curve is positively skewed with a median of 0.16, indicating a highly flashy flow regime, driven by runoff.

The timing of annual extreme water conditions can provide an indication of seasonality and predictability of flow events within a system. Figure 4.29 shows the distribution of the Julian day for the annual 1-day flow minima and maxima which provide a measure of the seasonal timing of low and high flows. It is important to note that Julian day for the minimum flow value begins on 01 July each year to avoid splitting the summer low flow period across water years. This means that Julian day for minimum flows is shifted by six months relative to the Julian day for maximum flows, for which the water year starts on 01 January. The Julian day for the 1-day low flow event usually occurs (approximately two-thirds of the time) during late summer or early autumn (February-April), with the median date being in late February. The timing of the 1-day high flow event typically falls in June or July, with a median of late June. However, there is greater variability in the timing of the high flow event with the range between the 16th and 84th percentiles stretching across 7 months (March-September), compared to 3 months for the low flow event.

Low and high pulse events are defined as those events with a peak flow greater than the 75th or 25th flow exceedance percentiles respectively. They represent different magnitude flushing flow events. Figure 4.30 displays the density distribution of the number of low and high flow pulses. Both display a similar range of variability, but the median number of high pulses (13.5) is greater than low pulses (9.0).

Figure 4.31 shows a density plot for the number of flow reversals, which is the number of days when flow switches between increasing and decreasing. This gives an indication of the frequency of changes in flow experienced. The median number of days on which reversals occur is 109.5 and on average 2 in every 3 years will be within approximately ±10% of the median.

Table 4.4: Summary of flow variability parameters for the Ohinemuri River at Karangahake.

	Minimum	16th percentile	33rd percentile	Median	67th percentile	84th percentile	Maximum
Median flow ($m^3 s^{-1}$), Jan	1.67	2.16	3.03	3.32	3.84	5.41	30.50
Median flow ($m^3 s^{-1}$), Feb	1.36	1.92	2.38	2.94	3.67	5.72	12.67
Median flow ($m^3 s^{-1}$), Mar	1.51	2.18	2.81	3.09	4.69	7.53	23.82
Median flow ($m^3 s^{-1}$), Apr	1.84	2.41	3.33	5.09	6.14	10.00	21.86
Median flow ($m^3 s^{-1}$), May	2.29	3.92	5.49	6.20	8.75	11.08	19.78
Median flow ($m^3 s^{-1}$), Jun	3.11	6.24	8.73	10.44	14.85	18.20	28.65
Median flow ($m^3 s^{-1}$), Jul	5.18	8.49	11.11	13.27	15.92	21.99	32.91
Median flow ($m^3 s^{-1}$), Aug	3.76	8.44	10.36	12.44	16.18	18.95	26.16
Median flow ($m^3 s^{-1}$), Sep	3.55	6.07	8.22	10.40	11.29	13.23	19.49
Median flow ($m^3 s^{-1}$), Oct	3.65	4.70	5.51	6.80	9.12	11.89	21.95
Median flow ($m^3 s^{-1}$), Nov	2.53	3.59	4.24	4.82	5.49	6.72	18.01
Median flow ($m^3 s^{-1}$), Dec	2.11	2.84	3.33	4.25	5.22	6.98	27.42
1 Day Flow Mins ($m^3 s^{-1}$)	1.11	1.50	1.69	1.84	1.89	2.01	2.98
1 Day Flow Maxs ($m^3 s^{-1}$)	67.03	121.6	152.8	196.4	234.7	307.2	663.3
3 Day Flow Mins ($m^3 s^{-1}$)	1.15	1.53	1.70	1.87	1.96	2.05	3.04
3 Day Flow Maxs ($m^3 s^{-1}$)	43.45	80.12	95.85	115.7	133.5	173.4	430.9
7 Day Flow Mins ($m^3 s^{-1}$)	1.17	1.57	1.78	1.94	2.08	2.22	3.21
7 Day Flow Maxs ($m^3 s^{-1}$)	27.97	50.31	56.51	70.22	81.13	103.1	232.1
30 Day Flow Mins ($m^3 s^{-1}$)	1.41	1.92	2.13	2.31	2.51	2.84	5.12
30 Day Flow Maxs ($m^3 s^{-1}$)	16.25	23.72	31.79	34.74	39.55	43.96	70.27
90 Day Flow Mins ($m^3 s^{-1}$)	1.69	2.67	3.41	3.58	3.81	5.55	7.89
90 Day Flow Maxs ($m^3 s^{-1}$)	14.41	16.36	20.34	22.17	26.04	29.95	38.41
Base Flow Index	0.10	0.12	0.14	0.16	0.18	0.22	0.33
Julian day of min flow (Day 0 = 01 July)	50	215	224	237	271	294	324
Julian day of max flow (Day 0 = 01 January)	10	76	147	179	202	248	342
Number of low pulses	2.00	6.00	7.00	9.00	13.00	14.00	16.00
Median duration low pulses (Days)	1.50	2.50	3.00	4.00	5.57	11.38	178.5
Number of high pulses	8.00	12.00	13.00	13.50	16.00	19.00	22.00
Median duration high pulses (Days)	1.50	2.12	3.00	3.75	4.00	5.00	7.00
Number of positive differences between days	75.00	86.00	89.00	91.00	95.13	99.76	113.0
Median of positive differences between days	0.36	0.70	0.84	1.16	1.35	1.96	3.48
Number of negative differences between days	252.0	266.0	268.0	272.5	275.0	279.8	290.0
Median of negative differences between days	-1.16	-0.89	-0.70	-0.62	-0.50	-0.44	-0.13
Reversals	65.00	96.48	104.0	109.5	112.3	118.5	132.0

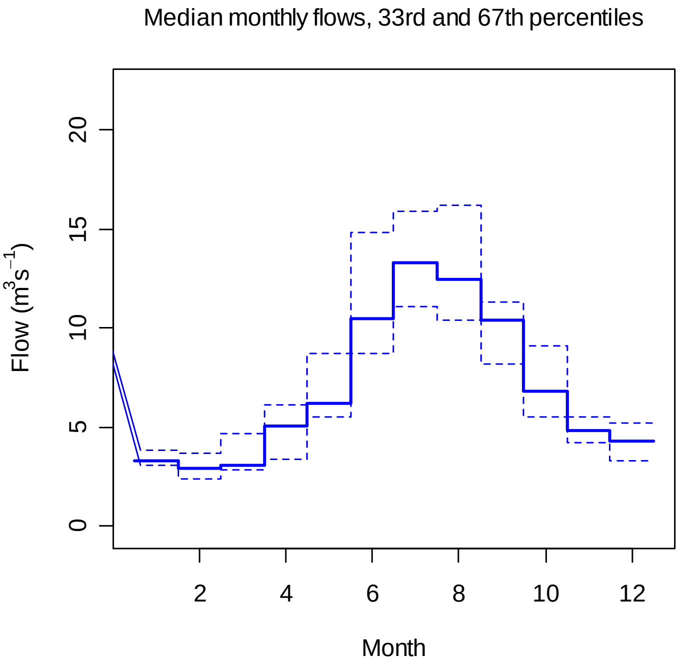

Figure 4.24: Plots of median (solid line) and 33rd and 67th percentile (dashed lines) monthly flows for the Ohinemuri River at Karangahake.

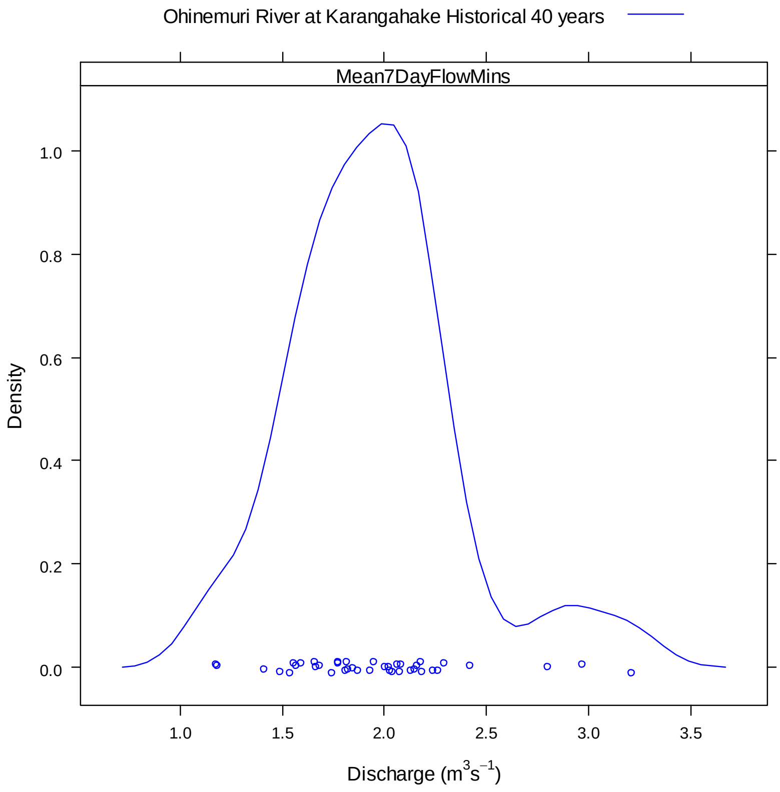

Figure 4.25: Density plot of mean 7-day flow minima for the Ohinemuri River at Karangahake.

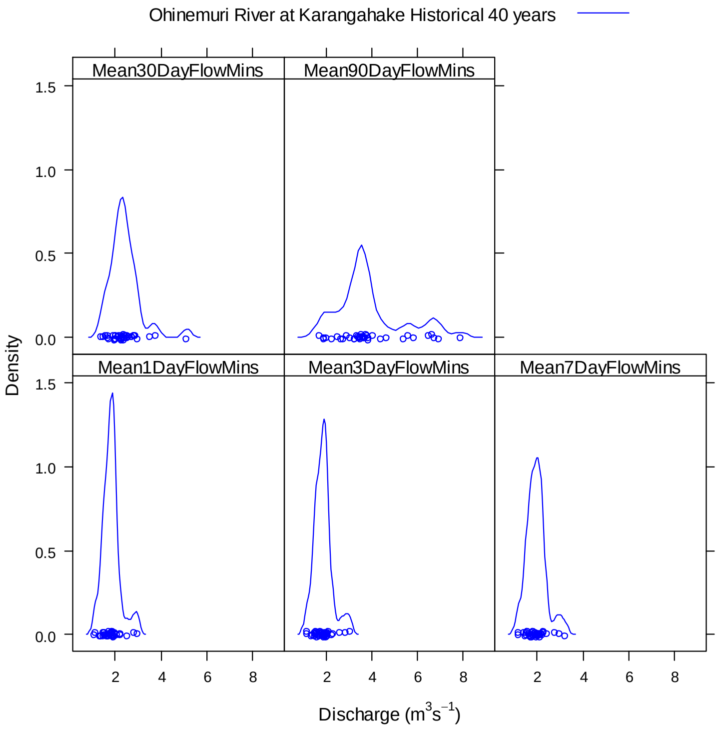

Figure 4.26: Density plots of mean flow minima for the Ohinemuri River at Karangahake.

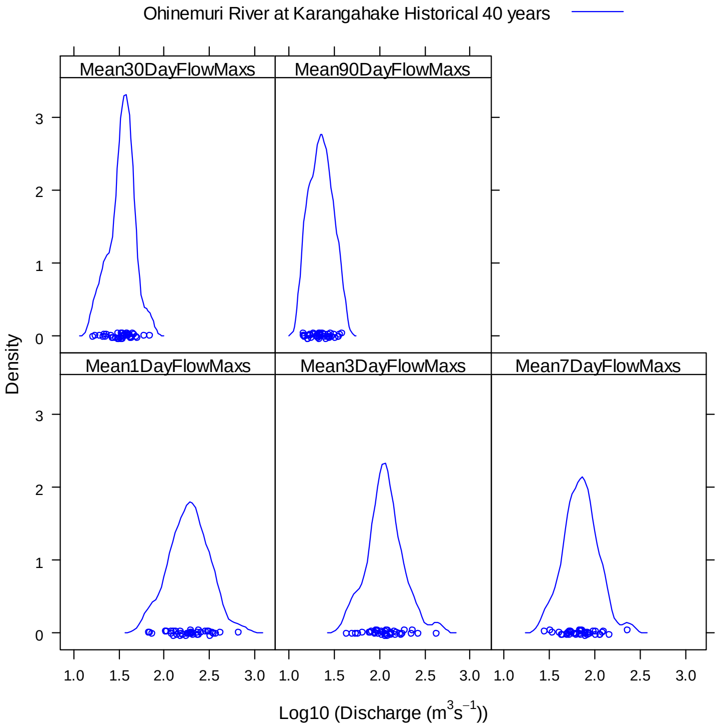

Figure 4.27: Density plots of mean flow maxima for the Ohinemuri River at Karangahake.

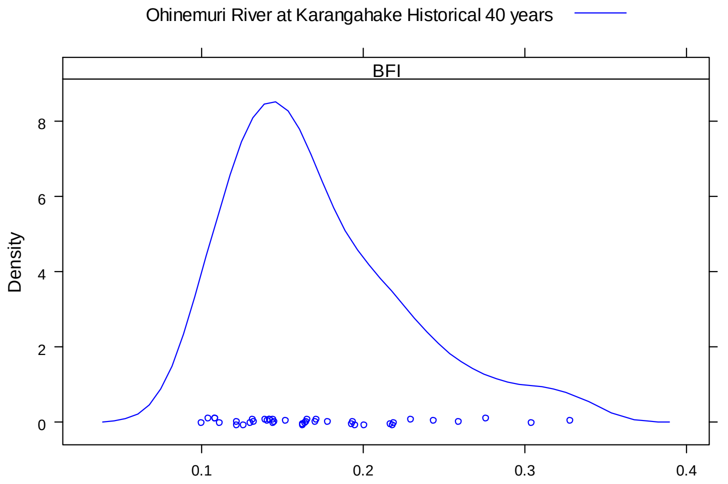

Figure 4.28: Density plot of mean annual base flow index for the Ohinemuri River at Karangahake.

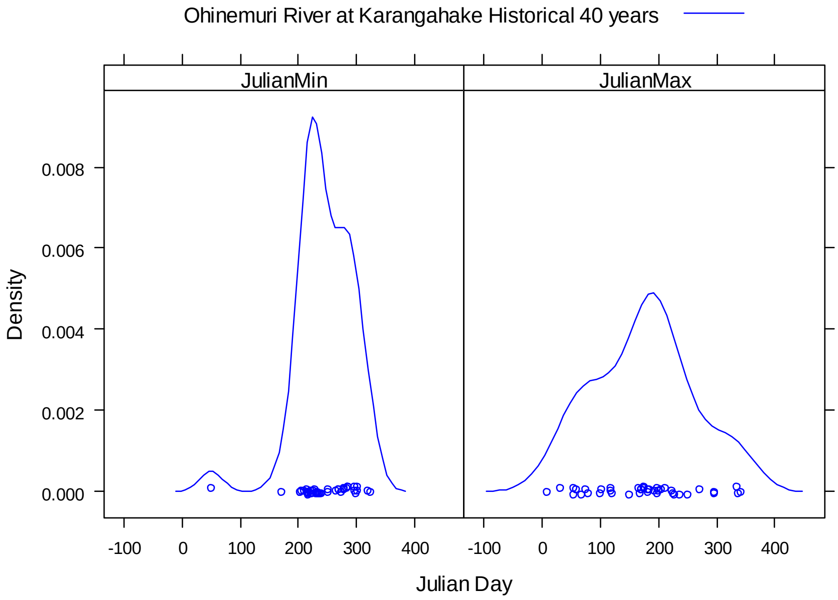

Figure 4.29: Density plots of Julian day of annual 1-day flow minimum and maximum for the Ohinemuri River at Karangahake. (Note: Water year for flow minimum starts 01 July and for flow maximum water year starts at 01 January).

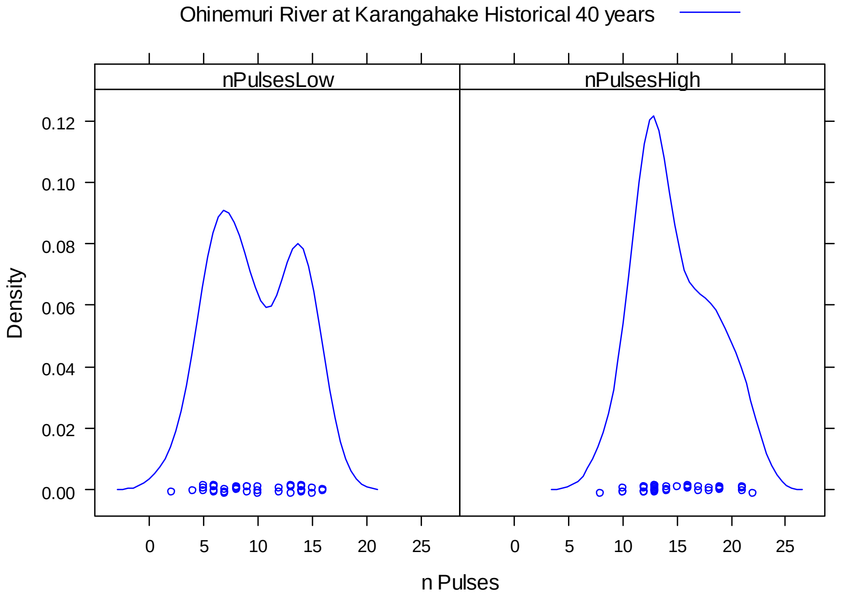

Figure 4.30: Density plots of the number of low and high flow pulses for the Ohinemuri River at Karangahake.

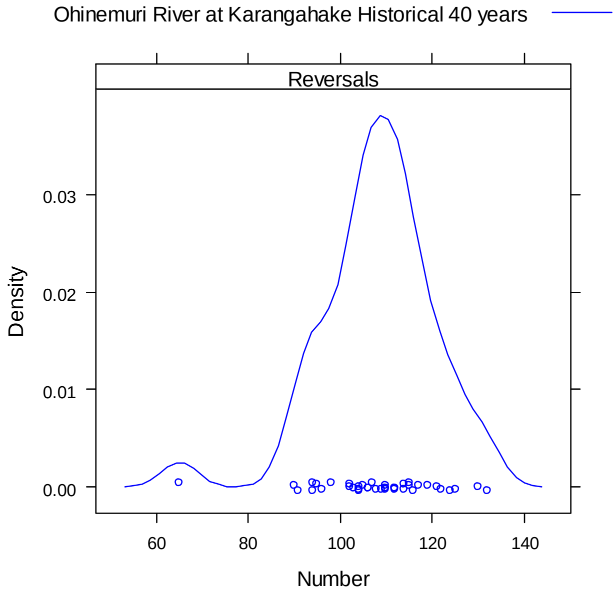

Figure 4.31: Density plot of the number of flow reversals for the Ohinemuri River at Karangahake.

Ohinemuri River at Queen's Head

Table 4.5 summarises the hydrologic parameters calculated for the flow record from the Ohinemuri River at Queen's Head. Figure 4.32 to Figure 4.39 illustrate the distribution of some of the key parameters that could be used to inform flow management decisions.

Figure 4.32 compares the median monthly flows for the Ohinemuri River at Queen's Head. A similar seasonal pattern to that observed at the Karangahake gauge is apparent with the summer period being characterised by a relatively narrow range of flows compared to the wide range experienced over the winter months, and transitional periods over autumn and spring. The lowest median flow is however experienced in March at 1.20 $m^3 s^{-1}$, which is equivalent to 20% of the highest median flow in July.

The distribution of the mean 7-day low flow parameter is shown in Figure 4.33. The median value is 0.68 $m^3 s^{-1}$. There is slightly greater variability in the median value compared to the Karangahake gauge downstream. Figure 4.34 shows the distribution of the other low flow statistics, illustrating a relative similarity in the distribution of the mean 1, 3 and 7-day low flows.

Figure 4.35 shows the distribution of the high flow statistics for the Ohinemuri River at Queen's Head. As would be expected, the variability in peak flow narrows with increasing event duration as the influence of extreme events is reduced. The median 1-day maximum flow is 83.03 $m^3 s^{-1}$. On average, every 1 in 3 years the maximum flow will be between 85% and 125% of this value. The median 7-day flow maximum is 29.98 $m^3 s^{-1}$, and this statistic shows greater between-year consistency with on average 1 in every 3 years falling between 96% and 113% of the median.

Figure 4.36 shows the distribution of BFI over the duration of the flow record. The results are more evenly distributed than for the Karangahake gauge, but the median value is still low at 0.13 indicating a highly flashy, precipitation driven flow regime.

Figure 4.37 shows the distribution of the Julian day of annual 1-day flow minima and maxima. The Julian day of the 1-day low flow events again typically occurs during the late summer to early autumn period. The median date is in late February and on average 1 in 3 years the 1-day low flow occurs between mid-February and mid-March. The timing of the 1-day high flow event is on average slightly earlier than further downstream at Karangahake. The median date is June and, on average, 1 in 3 years will be between mid-May and mid-July.

Figure 4.38 displays the distribution of the number of low and high flow pulses. Both display a similar range of variability, but the median number of high pulses (12.0) is greater than low pulses (8.0). Figure 4.39 shows a density plot for the number of flow reversals. The median number of days on which reversals occur is 106.0 and on average 2 in every 3 years will be within approximately ±8% of the median which is similar to the Ohinemuri at Karangahake.

Table 4.5: Summary of flow variability parameters for the Ohinemuri River at Queen's Head.

	Minimum	16th percentile	33rd percentile	Median	67th percentile	84th percentile	Maximum
Median flow ($m^3 s^{-1}$), Jan	0.60	0.72	0.94	1.30	1.47	2.69	15.20
Median flow ($m^3 s^{-1}$), Feb	0.36	0.77	1.01	1.32	1.57	2.77	7.85
Median flow ($m^3 s^{-1}$), Mar	0.59	0.82	1.06	1.20	1.51	3.68	13.11
Median flow ($m^3 s^{-1}$), Apr	0.75	0.86	1.12	2.26	2.97	3.87	8.70
Median flow ($m^3 s^{-1}$), May	0.77	1.76	2.24	3.08	3.85	4.78	10.21
Median flow ($m^3 s^{-1}$), Jun	0.98	2.68	3.71	4.55	5.97	7.87	8.35
Median flow ($m^3 s^{-1}$), Jul	2.33	3.97	4.97	5.94	7.72	11.40	15.36
Median flow ($m^3 s^{-1}$), Aug	2.22	4.19	4.79	5.32	7.54	8.42	11.13
Median flow ($m^3 s^{-1}$), Sep	2.09	2.70	3.89	5.36	5.79	7.15	17.78
Median flow ($m^3 s^{-1}$), Oct	1.39	2.00	2.76	3.31	4.25	7.64	10.61
Median flow ($m^3 s^{-1}$), Nov	0.94	1.51	1.74	1.89	2.22	2.71	9.59
Median flow ($m^3 s^{-1}$), Dec	0.71	0.91	1.01	1.64	2.17	3.62	12.14
1 Day Flow Mins ($m^3 s^{-1}$)	0.32	0.46	0.55	0.63	0.68	0.72	0.79
1 Day Flow Maxs ($m^3 s^{-1}$)	31.91	51.43	71.11	83.03	104.4	122.2	160.6
3 Day Flow Mins ($m^3 s^{-1}$)	0.33	0.48	0.56	0.64	0.69	0.74	0.86
3 Day Flow Maxs ($m^3 s^{-1}$)	20.39	32.87	48.11	52.29	55.00	70.30	83.93
7 Day Flow Mins ($m^3 s^{-1}$)	0.35	0.53	0.57	0.68	0.72	0.79	0.94
7 Day Flow Maxs ($m^3 s^{-1}$)	12.51	20.89	28.66	29.98	33.77	38.55	47.63
30 Day Flow Mins ($m^3 s^{-1}$)	0.37	0.68	0.76	0.80	0.90	1.02	1.54
30 Day Flow Maxs ($m^3 s^{-1}$)	8.51	11.91	13.74	15.71	17.45	20.21	21.78
90 Day Flow Mins ($m^3 s^{-1}$)	0.67	0.90	1.10	1.23	1.30	2.04	2.94
90 Day Flow Maxs ($m^3 s^{-1}$)	7.12	7.53	8.39	10.22	11.21	12.89	17.62
Base Flow Index	0.07	0.10	0.11	0.13	0.15	0.17	0.21
Julian day of min flow (Day 0 = 01 July)	130	210	230	240	258	297	322
Julian day of max flow (Day 0 = 01 January)	33	105	133	175	204	244	338
Number of low pulses	3.00	6.00	7.00	8.00	9.00	10.00	18.00
Median duration low pulses (Days)	1.50	2.00	3.00	4.00	7.48	11.22	80.00
Number of high pulses	8.00	9.52	10.00	12.00	13.00	15.00	18.00
Median duration high pulses (Days)	2.00	2.52	4.00	4.50	5.37	6.74	10.00
Number of positive differences between days	74.00	81.56	87.26	92.00	94.00	96.48	114.0
Median of positive differences between days	0.16	0.20	0.32	0.38	0.46	0.56	0.80
Number of negative differences between days	229.0	244.2	259.3	269.0	274.2	278.0	285.0
Median of negative differences between days	-0.46	-0.33	-0.26	-0.24	-0.19	-0.17	-0.14
Reversals	86.00	97.00	102.0	106.0	109.7	115.4	126.0

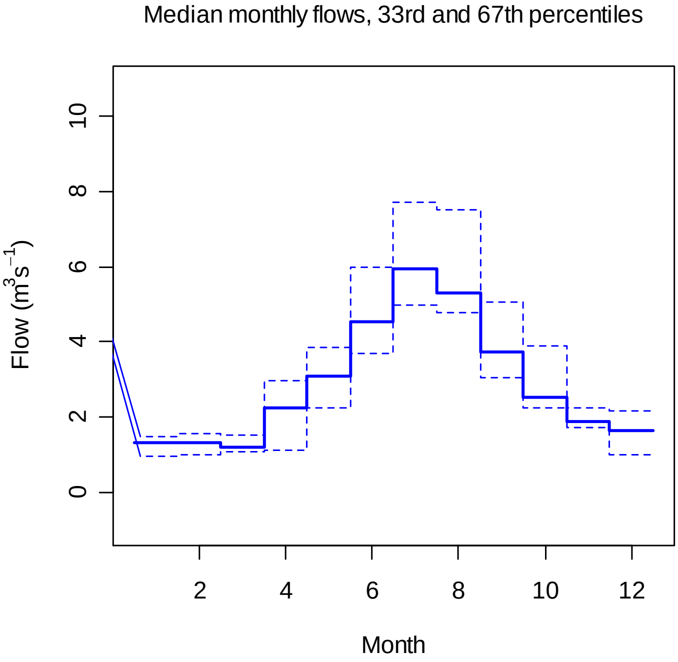

Figure 4.32: Plots of median (solid line) and 33rd and 67th percentile (dashed lines) monthly flows for the Ohinemuri River at Queen's Head.

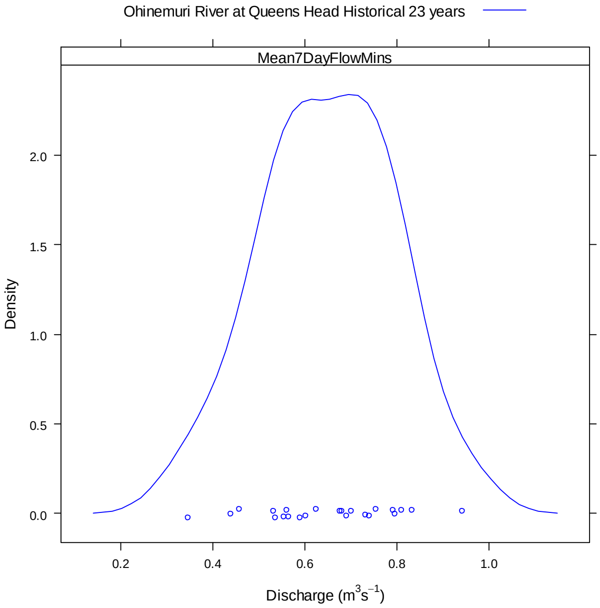

Figure 4.33: Density plot of mean 7-day flow minima for the Ohinemuri River at Queen's Head.

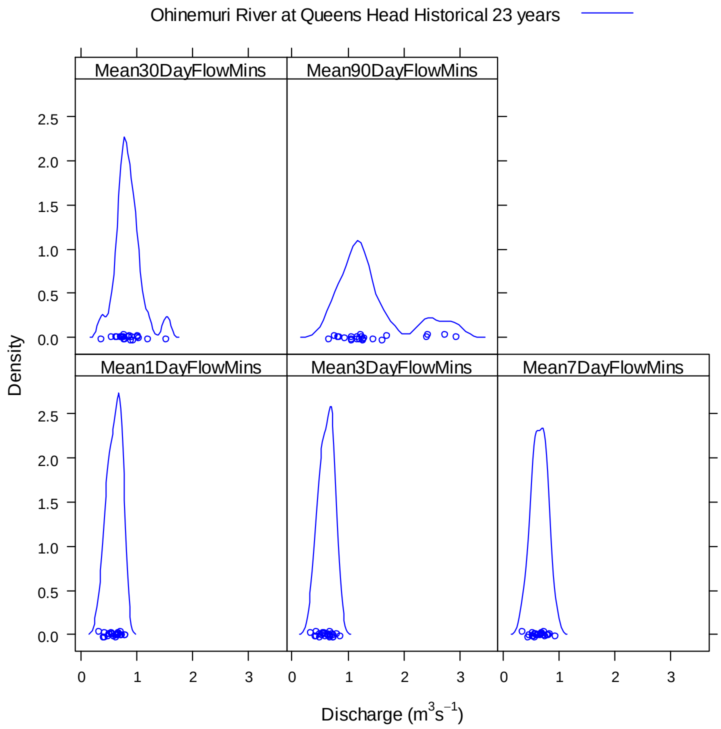

Figure 4.34: Density plots of mean flow minima for the Ohinemuri River at Queen's Head.

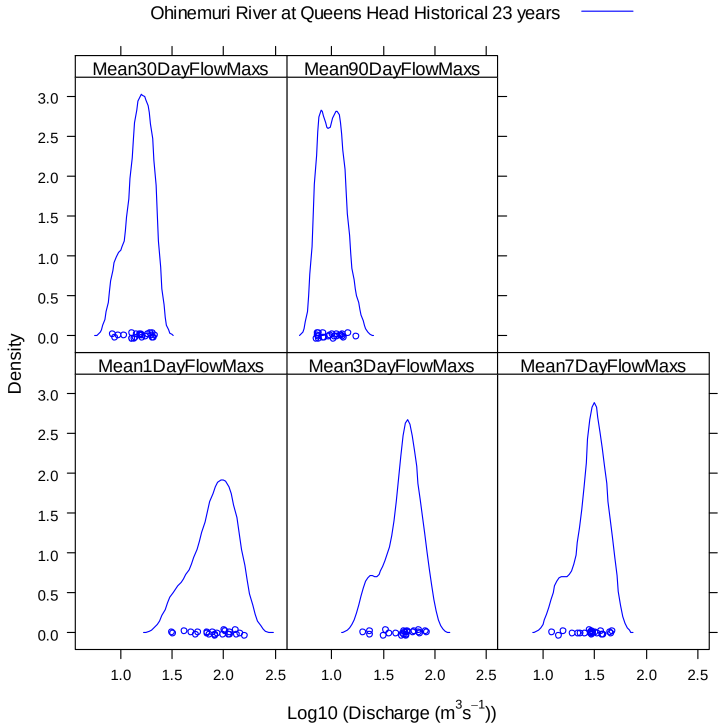

Figure 4.35: Density plots of mean flow maxima for the Ohinemuri River at Queen's Head.

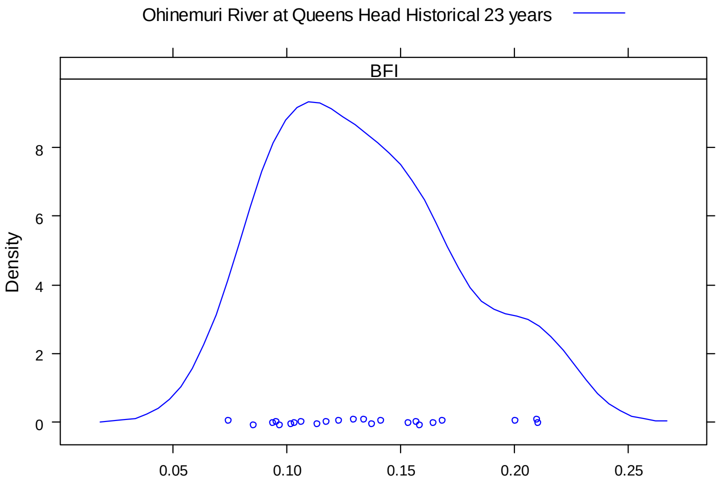

Figure 4.36: Density plot of mean base flow index for the Ohinemuri River at Queen's Head.

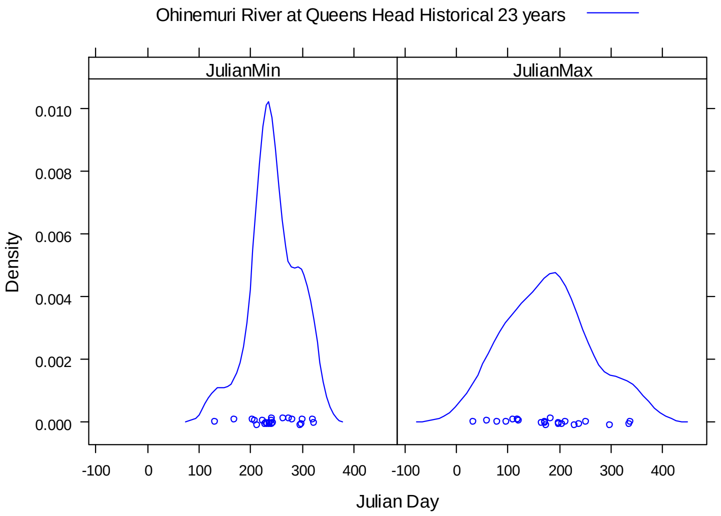

Figure 4.37: Density plots of Julian day of annual 1-day flow minimum and maximum for the Ohinemuri River at Queen's Head. Note: Water year for flow minimum starts 01 July and for flow maximum water year starts at 01 January.

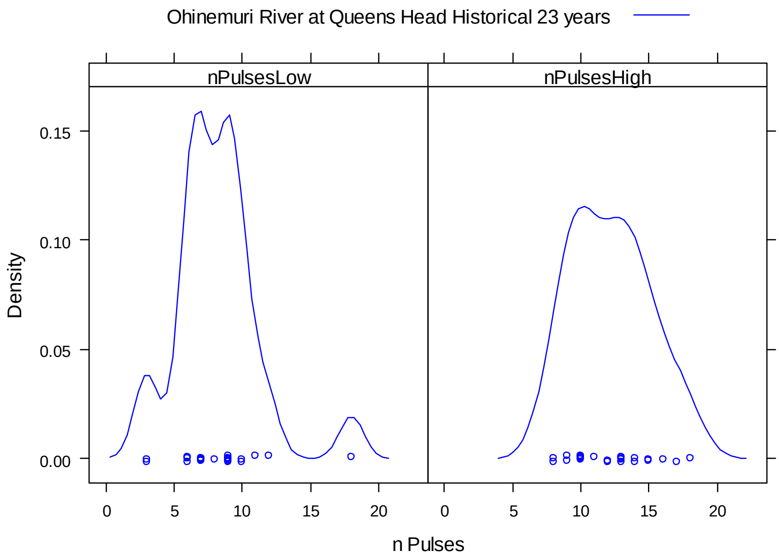

Figure 4.38: Density plots of the number of low and high flow pulses for the Ohinemuri River at Queen's Head.

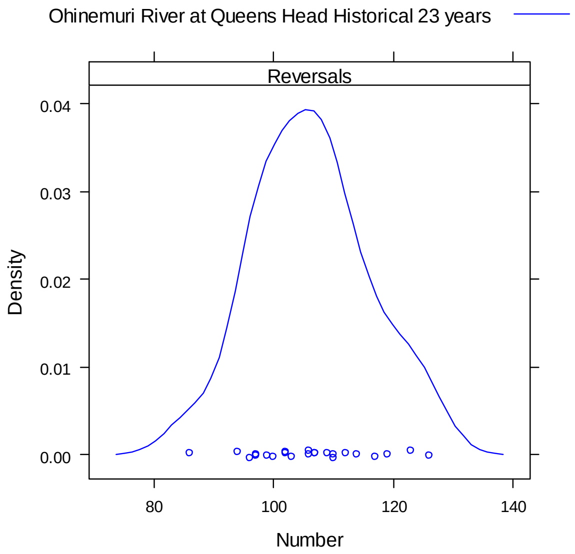

Figure 4.39: Density plot of the number of flow reversals for the Ohinemuri River at Queen's Head.

Oraka Stream at Pinedale

Table 4.6 summarises the hydrologic parameters calculated for the flow record from the Oraka Stream at Pinedale. Figure 4.40 to Figure 4.47 illustrate the distribution of some of the key parameters that can be used for informing flow management decisions. The Oraka Stream can be considered representative of the upper Waihou catchment.

Figure 4.40 compares the median monthly flows for the Oraka Stream. It can be seen that there is a much less distinct seasonal pattern compared to the Ohinemuri River. The range and magnitude of flows varies relatively little between months. The lowest median flow of 2.40 $m^3 s^{-1}$ occurs in March and the highest of 2.98 $m^3 s^{-1}$ in October.

The distribution of the mean 7-day low flow parameter is shown in Figure 4.41. The median value is 2.22 $m^3 s^{-1}$. On average, approximately 2 in 3 years will have a 7-day low flow within ±15% of the median indicating a relatively low level of inter-annual variability in low flows. This is also observed in the other low flow statistics (Figure 4.42).

Figure 4.43 shows the distribution of the high flow statistics. As would be expected, the variability in peak flow narrows with increasing event duration as the influence of extreme events is reduced. The median 1-day maximum flow is 8.23 $m^3 s^{-1}$. On average, every 1 in 3 years the maximum flow will be between 90% and 114% of this value. The median 7-day flow maximum is 4.67 $m^3 s^{-1}$, and this statistic shows similar between year consistencies.

Figure 4.44 shows the distribution of BFI over the duration of the flow record. The median BFI for the Oraka Stream (0.81) is considerably higher than for the Ohinemuri Stream, reflecting the dominance of groundwater to overall flow in the upper Waihou catchment. This results in a much more stable, less flashy flow regime.

Figure 4.45 shows the distribution of the Julian day of annual 1-day flow minima and maxima. The Julian day of the 1-day low flow event typically occurs between February and May, with the median date being at the beginning of April. The timing of the 1-day high flow event usually falls between mid-winter and mid-spring. The median day is early August and is likely to reflect the extent of winter recharge of the aquifer and subsequent break-through of springs.

Figure 4.46 displays the distribution of the number of low and high flow pulses. The number of low pulses displays a negative skew towards a single low pulse event. This is an artefact of the IHA calculations and narrow range of variability in flows at this site, meaning that there are several years when flows were greater than the low pulse threshold for the majority or whole of the year. It is estimated that this may occur on average nearly 1 in every 3 years. The median number of high pulses is 15.0, with a median duration of 2.0 days. Figure 4.47 shows a density plot for the number of flow reversals. The median number of days on which reversals occur is 120.0, but the magnitude of the differences between days is low with the median positive difference between days being 0.07 and the median negative difference between days being -0.04.

Table 4.6: Summary of flow variability parameters for the Oraka Stream at Pinedale.

	Minimum	16th percentile	33rd percentile	Median	67th percentile	84th percentile	Maximum
Median flow ($m^3 s^{-1}$), Jan	1.91	2.19	2.39	2.53	2.74	3.01	3.62
Median flow ($m^3 s^{-1}$), Feb	1.97	2.14	2.30	2.47	2.70	2.85	3.72
Median flow ($m^3 s^{-1}$), Mar	1.97	2.09	2.32	2.40	2.63	2.75	3.33
Median flow ($m^3 s^{-1}$), Apr	1.86	2.15	2.35	2.42	2.53	2.78	3.34
Median flow ($m^3 s^{-1}$), May	1.94	2.15	2.31	2.46	2.73	2.90	3.34
Median flow ($m^3 s^{-1}$), Jun	2.08	2.23	2.44	2.77	3.04	3.25	3.79
Median flow ($m^3 s^{-1}$), Jul	2.06	2.26	2.51	2.76	3.04	3.61	4.20
Median flow ($m^3 s^{-1}$), Aug	2.01	2.26	2.63	2.83	3.20	3.55	4.31
Median flow ($m^3 s^{-1}$), Sep	2.18	2.45	2.63	2.79	3.07	3.31	4.64
Median flow ($m^3 s^{-1}$), Oct	2.06	2.28	2.65	2.98	3.32	3.41	4.57
Median flow ($m^3 s^{-1}$), Nov	2.03	2.23	2.44	2.66	2.82	2.94	3.35
Median flow ($m^3 s^{-1}$), Dec	1.99	2.26	2.41	2.56	2.82	3.08	3.40
1 Day Flow Mins ($m^3 s^{-1}$)	1.66	1.92	1.99	2.18	2.33	2.54	2.82
1 Day Flow Maxs ($m^3 s^{-1}$)	4.58	6.64	7.39	8.23	9.41	12.66	14.32
3 Day Flow Mins ($m^3 s^{-1}$)	1.71	1.93	2.00	2.20	2.36	2.55	2.85
3 Day Flow Maxs ($m^3 s^{-1}$)	3.95	4.90	5.88	6.15	7.09	8.11	12.13
7 Day Flow Mins ($m^3 s^{-1}$)	1.82	1.93	2.07	2.22	2.39	2.56	3.04
7 Day Flow Maxs ($m^3 s^{-1}$)	3.19	4.21	4.53	4.67	5.36	6.25	9.39
30 Day Flow Mins ($m^3 s^{-1}$)	1.85	2.06	2.21	2.34	2.44	2.65	3.23
30 Day Flow Maxs ($m^3 s^{-1}$)	2.37	3.24	3.45	3.65	3.96	4.49	5.48
90 Day Flow Mins ($m^3 s^{-1}$)	2.01	2.11	2.26	2.43	2.51	2.82	3.34
90 Day Flow Maxs ($m^3 s^{-1}$)	2.24	2.79	3.11	3.36	3.46	3.80	4.50
Base Flow Index	0.71	0.77	0.78	0.81	0.82	0.85	0.89
Julian day of min flow (Day 0 = 01 July)	1	104	231	278	307	321	360
Julian day of max flow (Day 0 = 01 January)	5	127	174	215	277	321	358
Number of low pulses	1.00	1.00	1.00	8.50	13.09	18.04	28.00
Median duration low pulses (Days)	2.00	3.00	3.91	6.25	351.2	365.0	366.0
Number of high pulses	4.00	9.32	12.00	15.00	17.00	21.68	29.00
Median duration high pulses (Days)	1.00	1.66	2.00	2.00	2.55	3.00	33.00
Number of positive differences between days	98.00	113.3	119.8	122.5	124.6	148.6	171.0
Median of positive differences between days	0.03	0.05	0.07	0.07	0.08	0.10	0.17
Number of negative differences between days	194.0	211.0	232.3	241.5	244.1	248.0	259.0
Median of negative differences between days	-0.12	-0.08	-0.05	-0.04	-0.04	-0.03	-0.03
Reversals	102.0	110.3	115.9	120.0	124.2	132.7	138.0

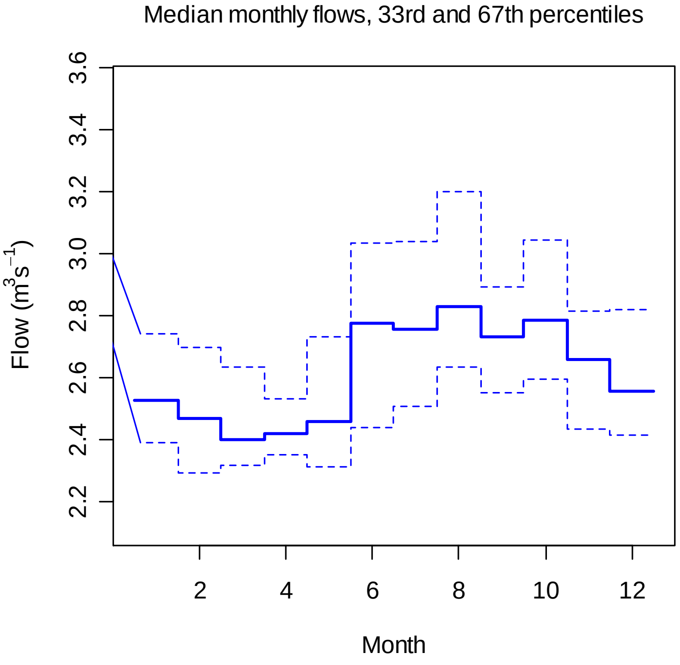

Figure 4.40: Plots of median (solid line) and 33rd and 67th percentile (dashed lines) monthly flows for the Oraka Stream at Pinedale.

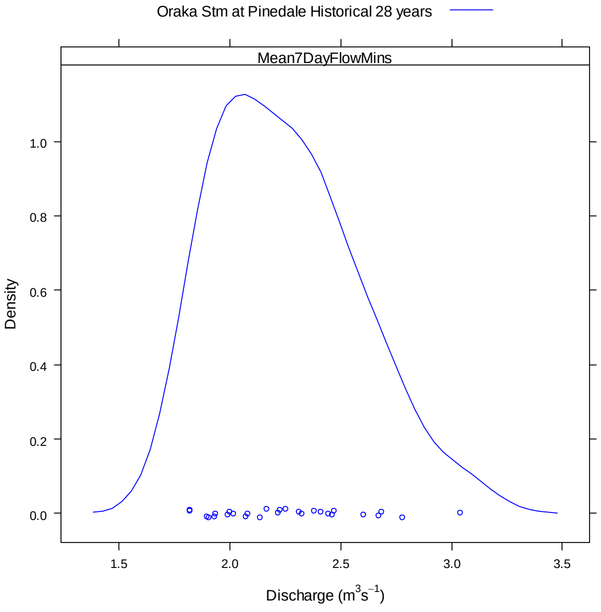

Figure 4.41: Density plot of mean 7-day flow minima for the Oraka Stream at Pinedale.

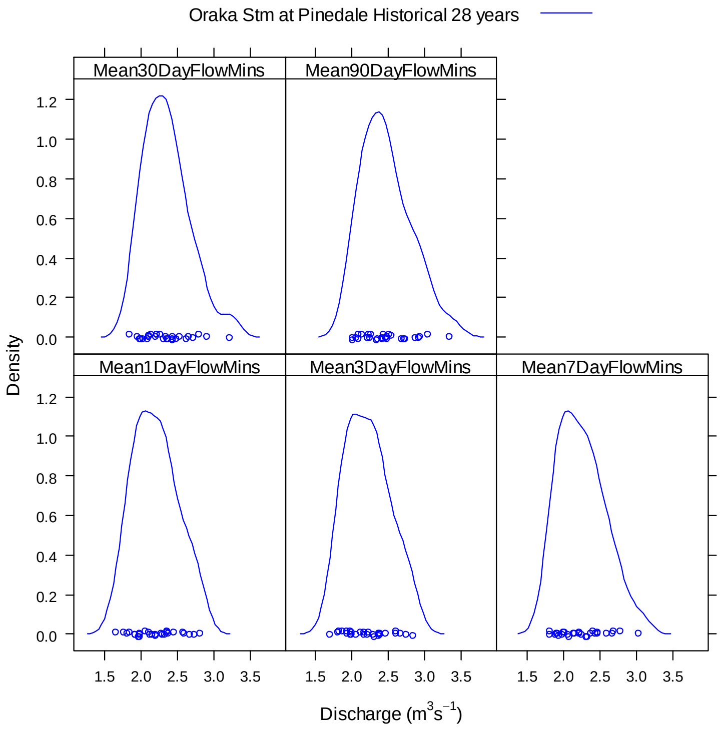

Figure 4.42: Density plots of mean flow minima for the Oraka Stream at Pinedale.

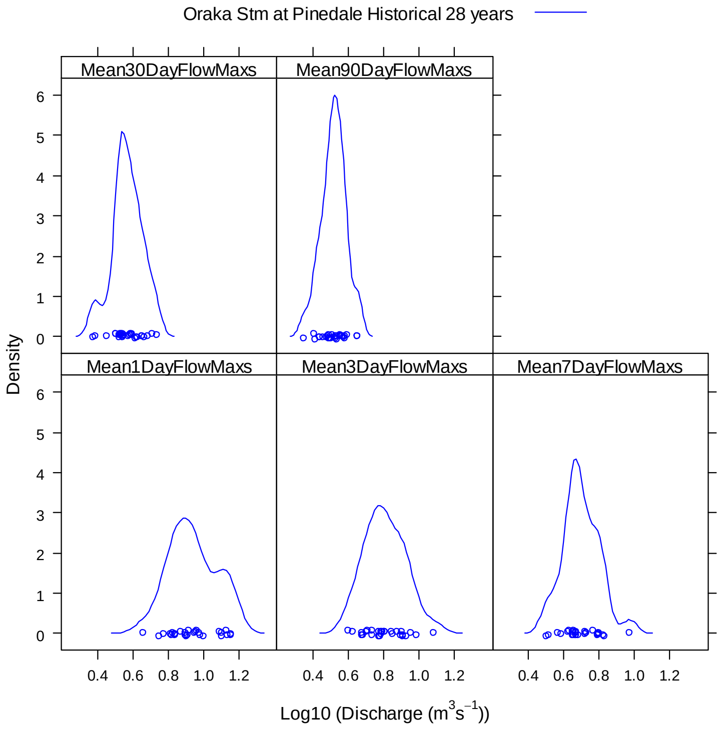

Figure 4.43: Density plots of mean flow maxima for the Oraka Stream at Pinedale.

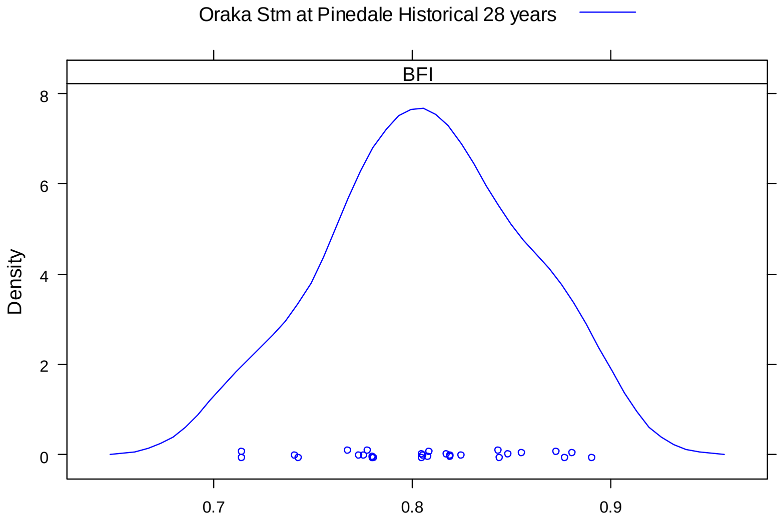

Figure 4.44: Density plot of mean base flow index for the Oraka Stream at Pinedale.

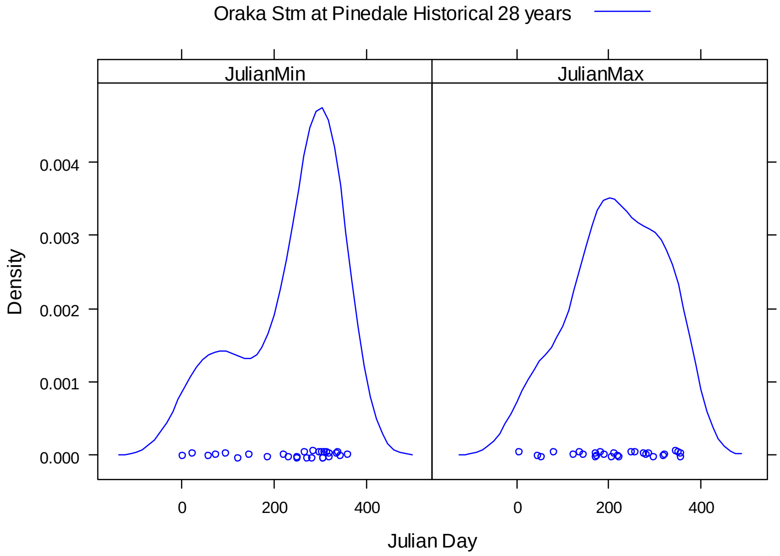

Figure 4.45: Density plots of Julian day of annual 1-day flow minimum and maximum for the Oraka Stream at Pinedale. Note: Water year for flow minimum starts 01 July and for flow maximum water year starts at 01 January.

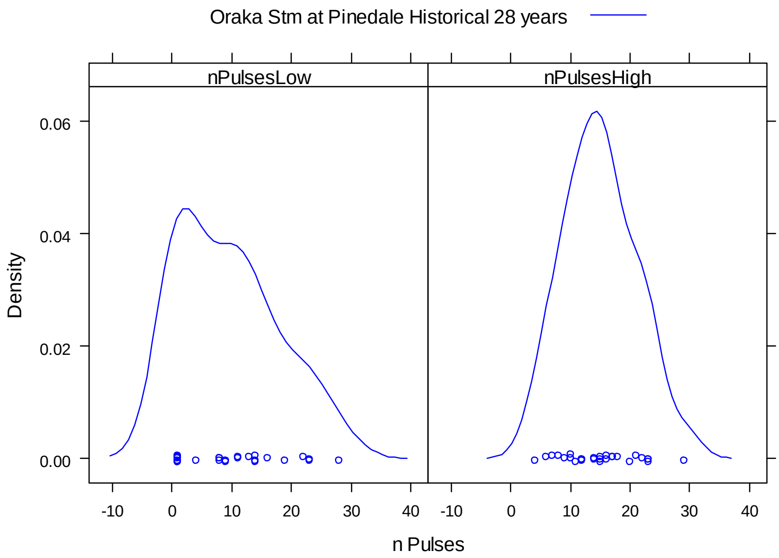

Figure 4.46: Density plots of the number of low and high flow pulses for the Oraka Stream at Pinedale.

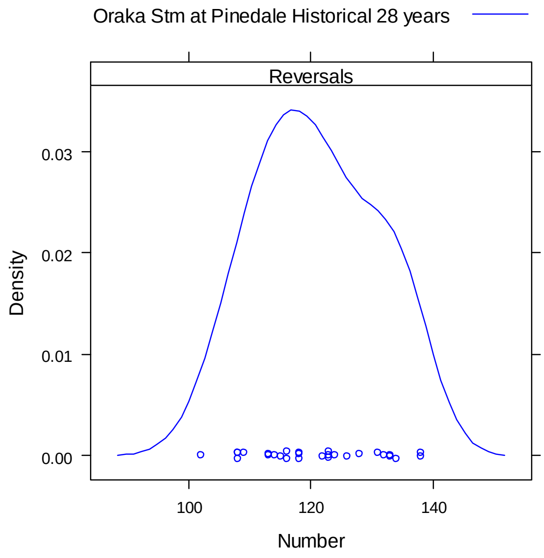

Figure 4.47: Density plot of the number of flow reversals for the Oraka Stream at Pinedale.

Waihou River at Okauia

Table 4.7 summarises the hydrologic parameters calculated for the flow record from the Waihou River at Okauia. Figure 4.48 to Figure 4.55 illustrate the distribution of some of the key parameters that can be used for informing flow management decisions. The Okauia gauge can be considered representative of the middle Waihou River combining the groundwater dominated tributaries from the upper catchment, but before the short, rainfall dominated streams draining the Kaimai ranges have significant influence on discharge.

Figure 4.48 compares the median monthly flows for the Waihou River at Okauia. Greater seasonality is again present in the monthly flows with relatively stable low flows during autumn, followed by greater variability during winter and spring. The lowest median flow of 21.40 m^3 s^{-1} occurs in April, but it is also noted that the median flow for March and May is very similar at 21.43 m^3 s^{-1} in both cases. The highest median monthly flow is 29.51 m^3 s^{-1} in August.

The distribution of the mean 7-day low flow parameter is shown in Figure 4.49. The median value is 19.92 m^3 s^{-1}. On average, approximately 2 in 3 years will have a 7-day low flow between 95% and 108% of the median indicating a low level of inter-annual variability in low flows. This is also observed in the other low flow statistics (Figure 4.50).

Figure 4.51 shows the distribution of the high flow statistics. As would be expected, the variability in peak flow narrows with increasing event duration as the influence of extreme events is reduced. The median 1-day maximum flow is 92.90 m^3 s^{-1}. On average, every 1 in 3 years the maximum flow will be between 89% and 106% of this value. The median 7-day flow maximum is 54.46 m^3 s^{-1}.

Figure 4.52 shows the distribution of BFI over the duration of the flow record. The median BFI for the Waihou River at Okauia (0.76) is considerably higher than for the Ohinemuri Stream, but is reduced compared to the Oraka Stream. The relatively high BFI reflects the influence of the groundwater driven flow regimes of the major tributaries of the upper Waihou catchment.

Figure 4.53 shows the distribution of the Julian day of annual 1-day flow minima and maxima. The Julian day of the 1-day low flow event occurs between the beginning of February and the end of April on average 2 in every 3 years, with the median date occurring in March. The timing of the 1-day high flow event usually falls in the June to October period, with the median day being in August.

Figure 4.54 displays the distribution of the number of low and high flow pulses. The number of low pulses displays a slightly bi-modal distribution, reflecting a separation between long periods when median flows did not fall below the low pulse threshold and hence the number of pulses was low, and periods when the median flow was lower and thus any small flushing flows registered as low pulses. The median number of low pulses is 13.0. The number of high pulses was more evenly distributed with a median of 15.0 pulses. The length of these pulses was generally short, with a maximum duration of 4.0 days. Figure 4.55 shows a density plot for the number of flow reversals. The median number of days on which reversals occur is 110.0.

Table 4.7: Summary of flow variability parameters for the Waihou River at Okauia.

	Minimum	16th percentile	33rd percentile	Median	67th percentile	84th percentile	Maximum
Median flow ($m^3 s^{-1}$), Jan	18.38	20.01	21.14	22.38	23.64	25.02	31.49
Median flow ($m^3 s^{-1}$), Feb	18.38	19.63	21.10	22.14	22.45	23.72	27.64
Median flow ($m^3 s^{-1}$), Mar	19.59	19.92	20.96	21.43	22.07	22.78	24.24
Median flow ($m^3 s^{-1}$), Apr	18.90	20.29	21.19	21.40	22.31	23.35	28.65
Median flow ($m^3 s^{-1}$), May	19.59	19.92	20.96	21.43	22.07	22.78	24.24
Median flow ($m^3 s^{-1}$), Jun	20.41	22.77	24.22	25.34	29.35	31.74	34.33
Median flow ($m^3 s^{-1}$), Jul	22.00	23.29	24.78	27.48	29.10	30.87	45.35
Median flow ($m^3 s^{-1}$), Aug	20.13	23.39	26.45	29.51	34.34	36.10	48.16
Median flow ($m^3 s^{-1}$), Sep	21.31	23.70	24.93	26.65	28.18	31.02	38.16
Median flow ($m^3 s^{-1}$), Oct	19.90	21.37	24.44	28.26	29.45	31.33	40.45
Median flow ($m^3 s^{-1}$), Nov	19.51	20.95	22.15	24.37	25.67	26.54	31.48
Median flow ($m^3 s^{-1}$), Dec	18.97	20.91	22.48	23.49	24.78	26.35	37.05
1 Day Flow Mins ($m^3 s^{-1}$)	17.83	18.51	19.03	19.75	20.14	21.48	22.82
1 Day Flow Maxs ($m^3 s^{-1}$)	58.69	73.60	83.07	92.90	98.90	112.8	152.8
3 Day Flow Mins ($m^3 s^{-1}$)	17.91	18.55	19.07	19.88	20.17	21.51	22.85
3 Day Flow Maxs ($m^3 s^{-1}$)	49.10	60.08	62.06	72.94	79.90	88.67	136.9
7 Day Flow Mins ($m^3 s^{-1}$)	17.99	18.90	19.18	19.92	20.35	21.56	23.11
7 Day Flow Maxs ($m^3 s^{-1}$)	39.28	44.34	49.58	54.46	61.38	63.47	112.4
30 Day Flow Mins ($m^3 s^{-1}$)	18.42	19.53	19.92	20.54	21.31	22.00	24.03
30 Day Flow Maxs ($m^3 s^{-1}$)	26.64	36.07	38.02	39.57	42.81	48.06	59.64
90 Day Flow Mins ($m^3 s^{-1}$)	19.07	20.29	21.14	21.80	22.35	23.33	25.12
90 Day Flow Maxs ($m^3 s^{-1}$)	25.18	30.74	32.31	33.61	34.94	38.30	47.23
Base Flow Index	0.65	0.70	0.75	0.76	0.78	0.80	0.83
Julian day of min flow (Day 0 = 01 July)	96	216	232	250	271	304	349
Julian day of max flow (Day 0 = 01 January)	10	167	202	222	254	298	358
Number of low pulses	1.00	2.68	4.92	13.00	15.08	19.16	22.00
Median duration low pulses (Days)	2.00	2.50	4.00	5.00	17.42	133.0	366.0
Number of high pulses	9.00	11.00	13.92	15.00	16.00	18.00	32.00
Median duration high pulses (Days)	1.50	2.00	2.00	2.50	3.00	3.08	4.00
Number of positive differences between days	94.00	101.4	106.0	110.0	111.1	113.3	123.0
Median of positive differences between days	0.52	0.68	0.77	0.92	1.11	1.23	2.40
Number of negative differences between days	232.0	248.7	253.0	253.0	257.1	263.6	272.0
Median of negative differences between days	-0.82	-0.74	-0.50	-0.48	-0.45	-0.40	-0.33
Reversals	94.00	102.0	107.9	110.0	114.0	120.0	136.0

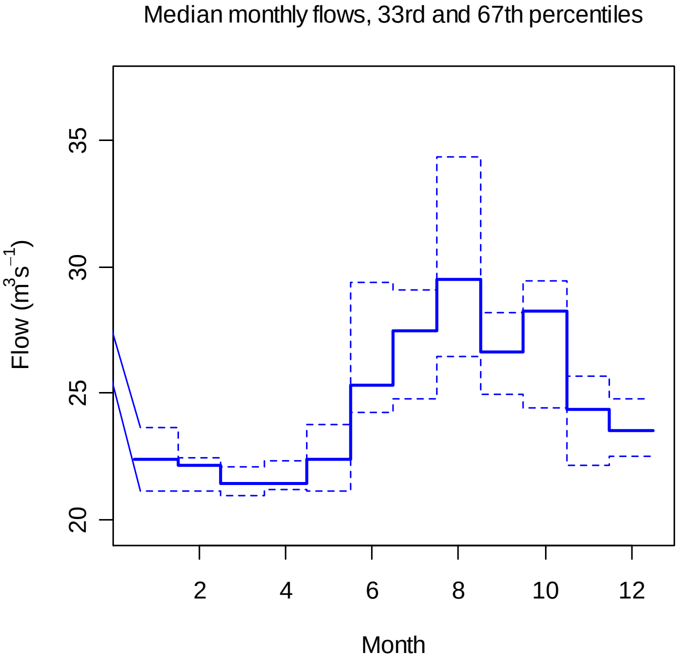

Figure 4.48: Plots of median (solid line) and 33rd and 67th percentile (dashed lines) monthly flows for the Waihou River at Okauia.

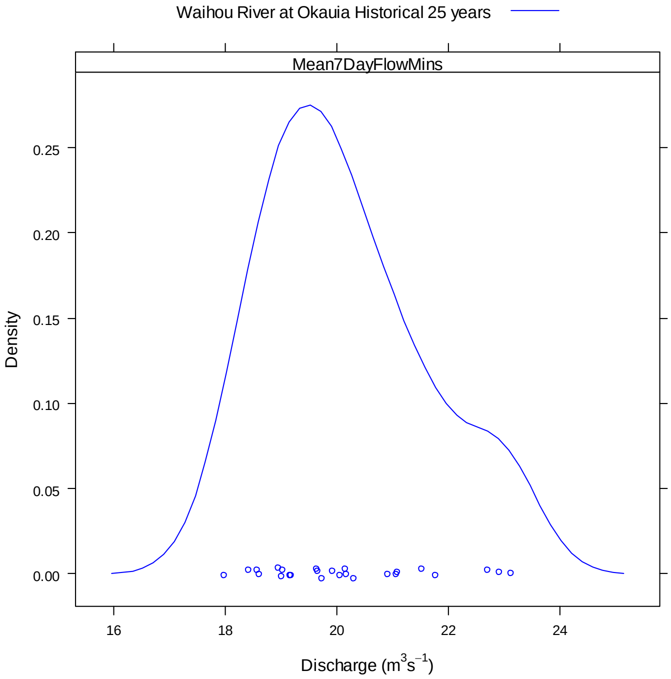

Figure 4.49: Density plot of mean 7-day flow minima for the Waihou River at Okauia.

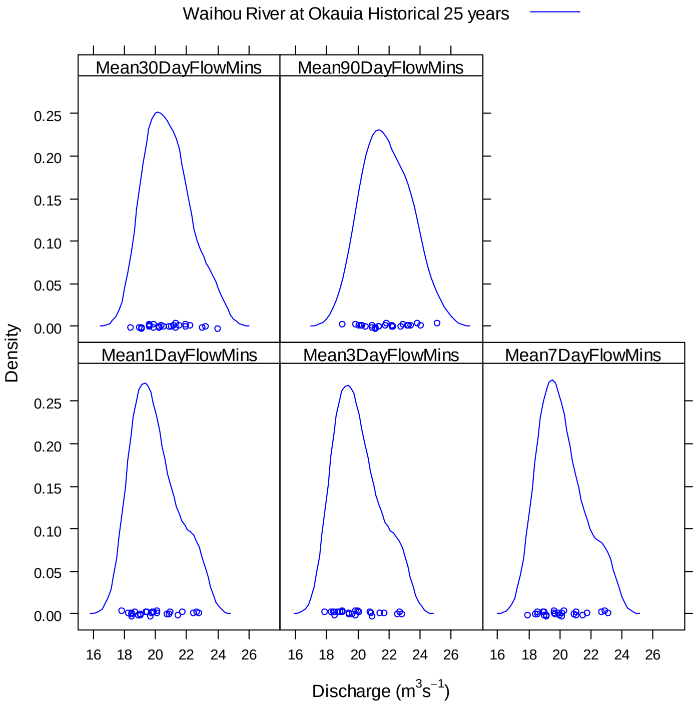

Figure 4.50: Density plots of mean flow minima for the Waihou River at Okauia.

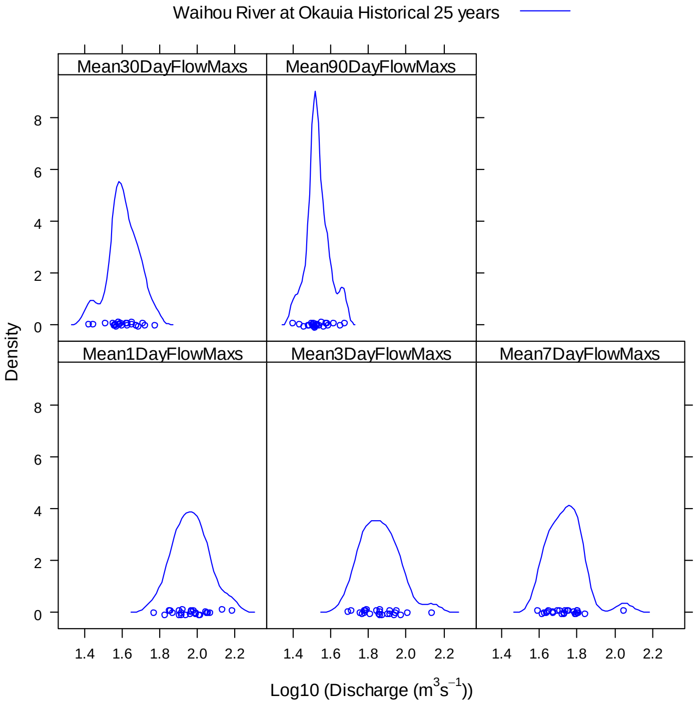

Figure 4.51: Density plots of mean flow maxima for the Waihou River at Okauia.

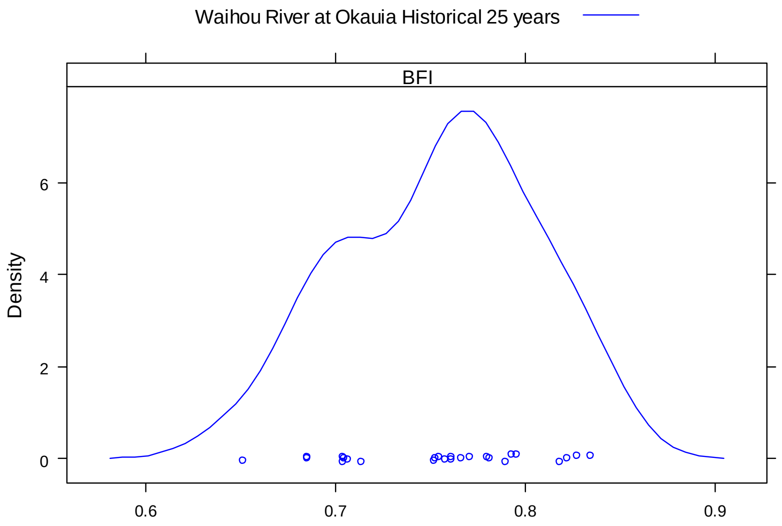

Figure 4.52: Density plot of mean base flow index for the Waihou River at Okauia.

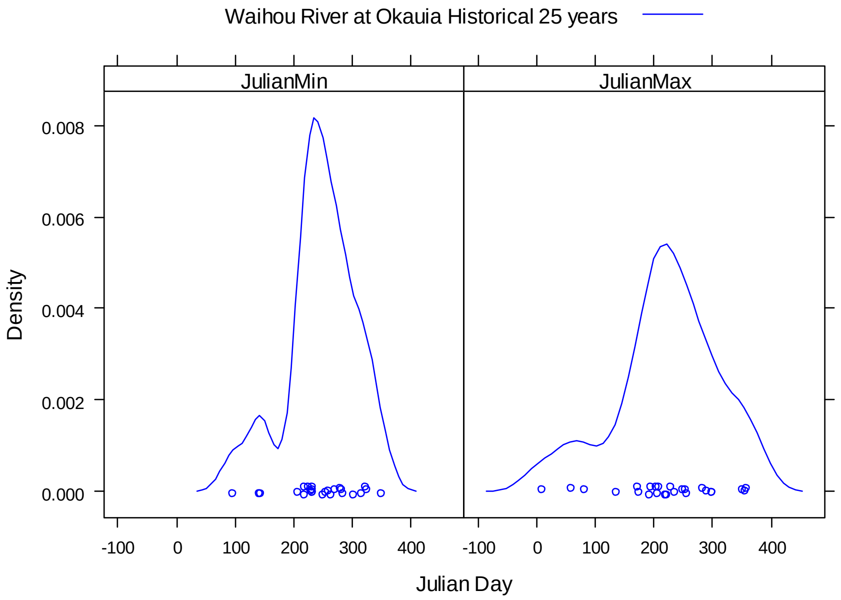

Figure 4.53: Density plots of Julian day of annual 1-day flow minimum and maximum for the Waihou River at Okauia. Note: Water year for flow minimum starts 01 July and for flow maximum water year starts at 01 January.

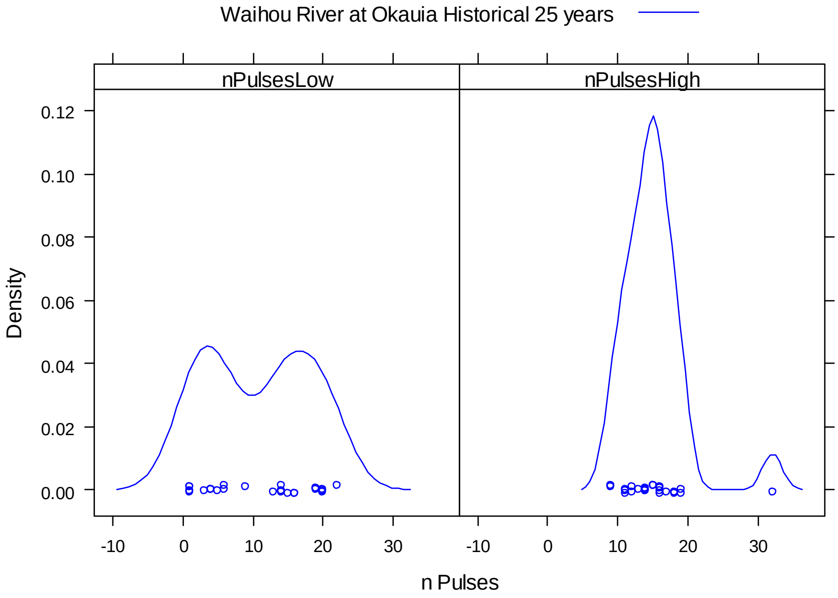

Figure 4.54: Density plots of the number of low and high flow pulses for the Waihou River at Okauia.

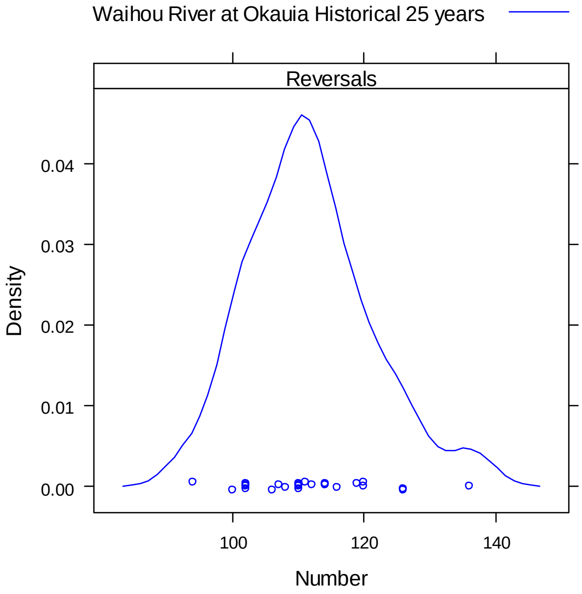

Figure 4.55: Density plot of the number of flow reversals for the Waihou River at Okauia.

Waihou River at Te Aroha

Table 4.8 summarises the hydrologic parameters calculated for the flow record from the Waihou River at Te Aroha. Figure 4.56 to Figure 4.63 illustrate the distribution of some of the key parameters that can be used for informing flow management decisions. The Te Aroha gauge can be considered representative of the middle Waihou River downstream of Okauia where the rainfall driven streams draining the Kaimai Ranges have increasing influence over flow dynamics in the Waihou River. The results for this site should be interpreted with caution due to the trends in the long-term flow records identified earlier. Trends in the data will be incorporated into the measures of variability calculated for the hydrologic parameters.

Figure 4.56 compares the median monthly flows for the Waihou River at Te Aroha. Greater seasonality is again present in the monthly flows with relatively stable low flows during autumn, followed by greater variability during winter and spring. The lowest median flow of 28.48 $m^3 s^{-1}$ occurs in February, which is 2 months earlier than for the Okauia gauge. The highest median monthly flow is 46.26 $m^3 s^{-1}$ in August.

The distribution of the mean 7-day low flow parameter is shown in Figure 4.57. The median value is 25.44 $m^3 s^{-1}$. On average, approximately 2 in 3 years will have a 7-day low flow between 95% and 111% of the median indicating a low level of inter-annual variability in low flows similar to the Okauia gauging site. This is also observed in the other low flow statistics (Figure 4.58).

Figure 4.59 shows the distribution of the high flow statistics. As would be expected, the variability in peak flow narrows with increasing event duration as the influence of extreme events is reduced. The median 1-day maximum flow is 165.7 $m^3 s^{-1}$. On average, every 1 in 3 years the maximum flow will be between 87% and 112% of this value. The median 7-day flow maximum is 114.6 $m^3 s^{-1}$.

Figure 4.60 shows the distribution of BFI over the duration of the flow record. The median BFI for the Waihou River at Te Aroha (0.64) is further reduced compared to the Waihou River at Okauia. This indicates an increasing contribution of runoff to overall flow in the river. There is a slightly bi-modality to the distribution. It is suggested that this may reflect a difference between drier and wetter years, with flows in drier years being dominated by the contribution of the groundwater driven tributaries in the upper catchment, and then the influence of the rainfall driven Kaimai streams increasing during wetter years.

Figure 4.61 shows the distribution of the Julian day of annual 1-day flow minima and maxima. The Julian day of the 1-day low flow event occurs between the beginning of February and the end of April on average 2 in every 3 years, with the median date occurring at the beginning of March. This is very similar to the Okauia gauging site. The timing of the median 1-day high flow event falls in July, and occurs in the June to August period on average 1 in every 3 years.

Figure 4.62 displays the distribution of the number of low and high flow pulses. The median number of low pulses is 8.0 and there was again at least one year when flow did not fall below the low pulse threshold for the whole year. This was however encountered less frequently at this site than the Okauia or Pinedale gauges. The median number of high pulses was 13.0 pulses. The median duration of the high pulses was 4.75 days with a maximum of 8.5. Figure 4.63 shows a density plot for the number of flow reversals. The median number of days on which reversals occur is 88.0 indicating a lower frequency of change than the upstream sites, which is slightly unexpected, but may reflect a longer duration of the rising and receding limbs of the hydrograph.

Table 4.8: Summary of flow variability parameters for the Waihou River at Te Aroha.

	Minimum	16th percentile	33rd percentile	Median	67th percentile	84th percentile	Maximum
Median flow ($m^3 s^{-1}$), Jan	24.21	26.74	27.84	29.84	30.77	35.26	61.32
Median flow ($m^3 s^{-1}$), Feb	24.95	26.07	26.94	28.48	31.79	33.00	38.30
Median flow ($m^3 s^{-1}$), Mar	24.58	26.23	27.85	29.12	30.14	33.32	59.10
Median flow ($m^3 s^{-1}$), Apr	24.32	27.37	28.39	30.24	31.75	34.18	53.55
Median flow ($m^3 s^{-1}$), May	23.59	27.32	28.96	31.86	35.22	40.12	47.96
Median flow ($m^3 s^{-1}$), Jun	27.39	31.31	35.09	37.57	42.01	50.03	64.29
Median flow ($m^3 s^{-1}$), Jul	29.67	34.14	38.61	42.38	48.56	55.66	74.68
Median flow ($m^3 s^{-1}$), Aug	28.84	34.66	42.41	46.26	51.83	56.64	80.41
Median flow ($m^3 s^{-1}$), Sep	28.21	33.32	36.97	41.17	47.01	50.99	77.88
Median flow ($m^3 s^{-1}$), Oct	26.52	29.73	34.87	38.03	42.04	47.84	67.71
Median flow ($m^3 s^{-1}$), Nov	24.68	28.01	31.29	33.54	35.22	38.21	49.82
Median flow ($m^3 s^{-1}$), Dec	24.46	28.32	31.13	32.33	33.46	36.76	68.02
1 Day Flow Mins ($m^3 s^{-1}$)	21.53	24.04	24.51	25.24	26.32	27.86	29.58
1 Day Flow Maxs ($m^3 s^{-1}$)	86.69	104.2	144.8	165.7	185.3	215.1	454.4
3 Day Flow Mins ($m^3 s^{-1}$)	21.62	24.08	24.60	25.35	26.38	27.95	29.58
3 Day Flow Maxs ($m^3 s^{-1}$)	83.44	101.4	132.0	145.0	154.9	187.7	278.1
7 Day Flow Mins ($m^3 s^{-1}$)	22.00	24.28	24.80	25.44	26.73	28.15	30.45
7 Day Flow Maxs ($m^3 s^{-1}$)	61.62	82.84	101.9	114.6	119.9	135.4	180.2
30 Day Flow Mins ($m^3 s^{-1}$)	23.92	25.26	25.61	26.42	27.71	28.98	31.36
30 Day Flow Maxs ($m^3 s^{-1}$)	42.88	54.52	63.95	69.89	75.34	82.85	99.70
90 Day Flow Mins ($m^3 s^{-1}$)	25.34	26.96	27.84	29.30	30.74	32.25	37.19
90 Day Flow Maxs ($m^3 s^{-1}$)	39.27	47.63	52.82	54.88	57.67	64.76	82.59
Base Flow Index	0.50	0.57	0.59	0.64	0.68	0.70	0.82
Julian day of min flow (Day 0 = 01 July)	174	214	233	245	271	296	327
Julian day of max flow (Day 0 = 01 January)	11	77	167	203	230	285	362
Number of low pulses	1.00	4.00	6.06	8.00	11.47	15.44	20.00
Median duration low pulses (Days)	2.00	4.00	5.77	8.75	12.91	40.86	366.0
Number of high pulses	3.00	10.00	11.53	13.00	14.00	16.00	20.00
Median duration high pulses (Days)	2.00	2.56	4.00	4.75	6.00	7.00	8.50
Number of positive differences between days	88.00	101.0	107.0	112.0	116.4	119.4	132.0
Median of positive differences between days	0.78	1.45	1.90	2.24	2.63	3.48	3.95
Number of negative differences between days	228.0	245.0	247.0	252.0	254.5	260.4	269.0
Median of negative differences between days	-1.84	-1.27	-1.12	-0.96	-0.83	-0.77	-0.48
Reversals	52.00	70.12	81.06	88.00	92.00	99.00	108.0

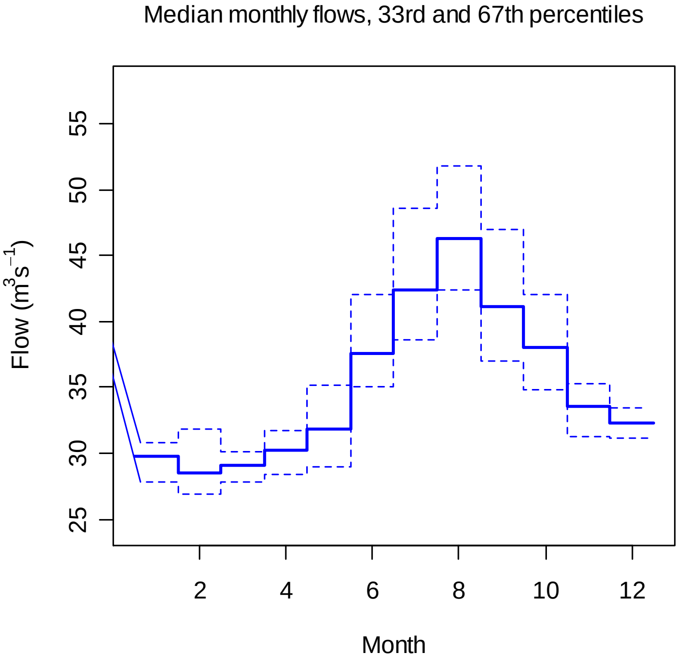

Figure 4.56: Plots of median (solid line) and 33rd and 67th percentile (dashed lines) monthly flows for the Waihou River at Te Aroha.

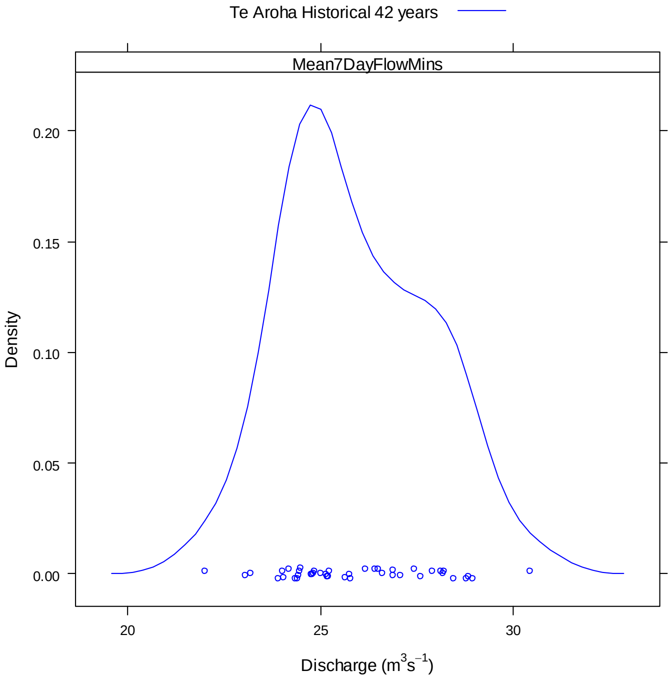

Figure 4.57: Density plot of mean 7-day flow minima for the Waihou River at Te Aroha.

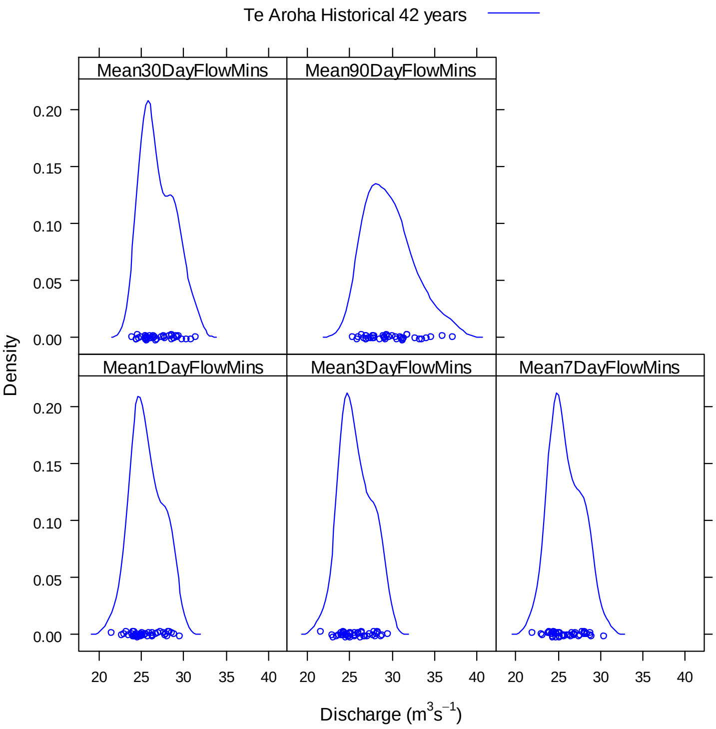

Figure 4.58: Density plots of mean flow minima for the Waihou River at Te Aroha.

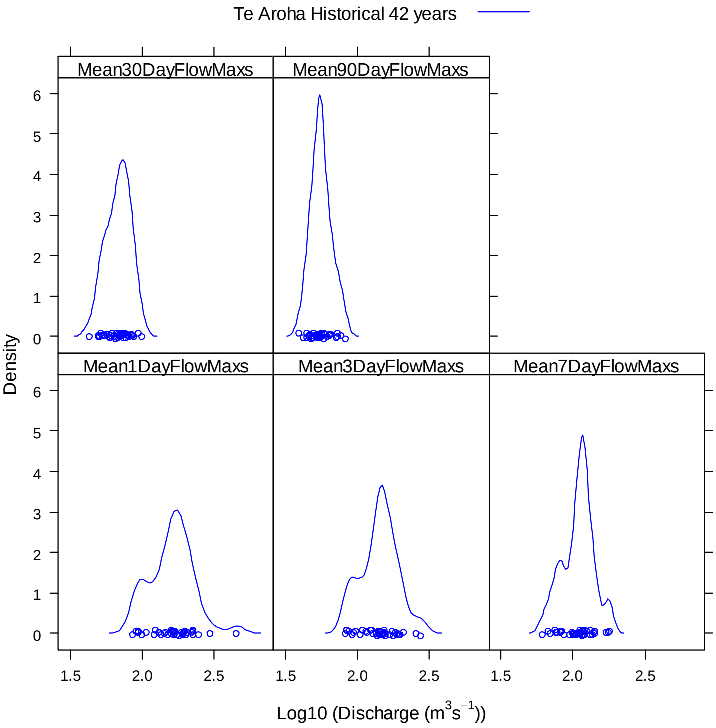

Figure 4.59: Density plots of mean flow maxima for the Waihou River at Te Aroha.

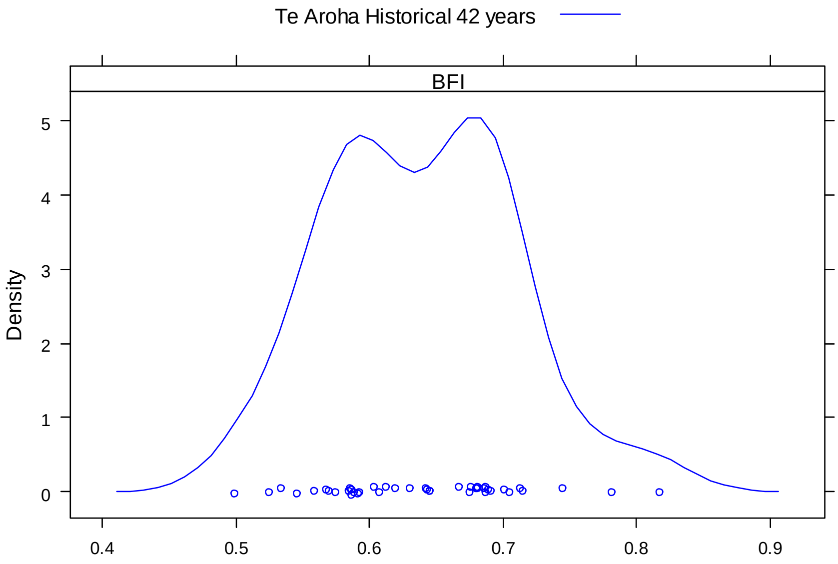

Figure 4.60: Density plot of mean base flow index for the Waihou River at Te Aroha.

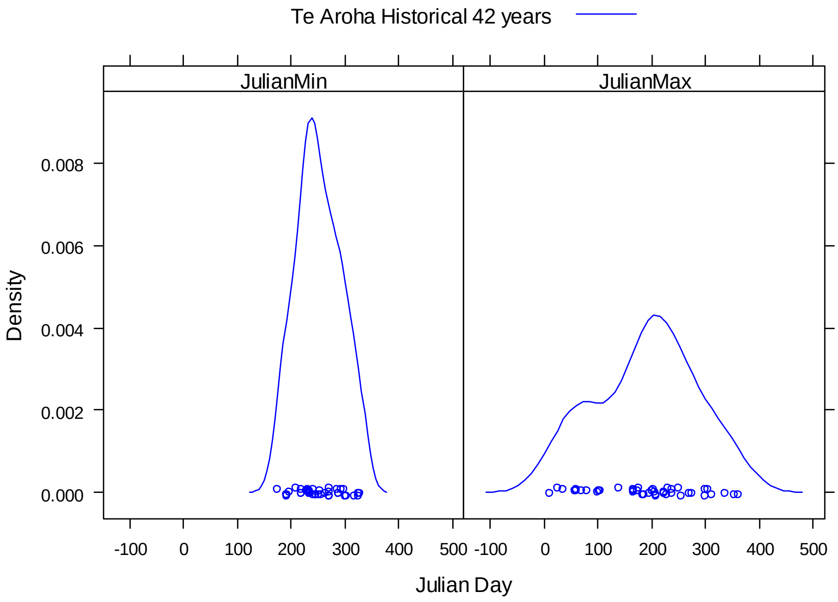

Figure 4.61: Density plots of Julian day of annual 1-day flow minimum and maximum for the Waihou River at Te Aroha. Note: Water year for flow minimum starts 01 July and for flow maximum water year starts at 01 January.

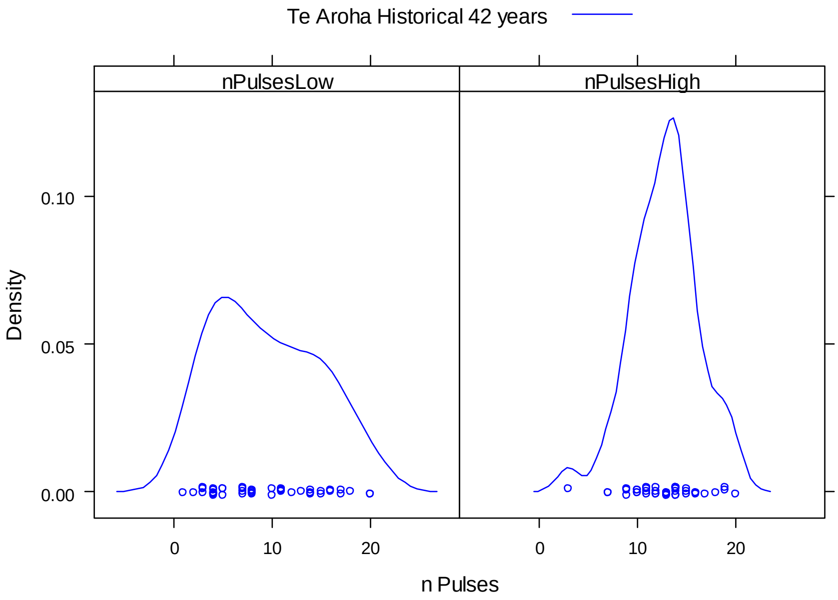

Figure 4.62: Density plots of the number of low and high flow pulses for the Waihou River at Te Aroha.

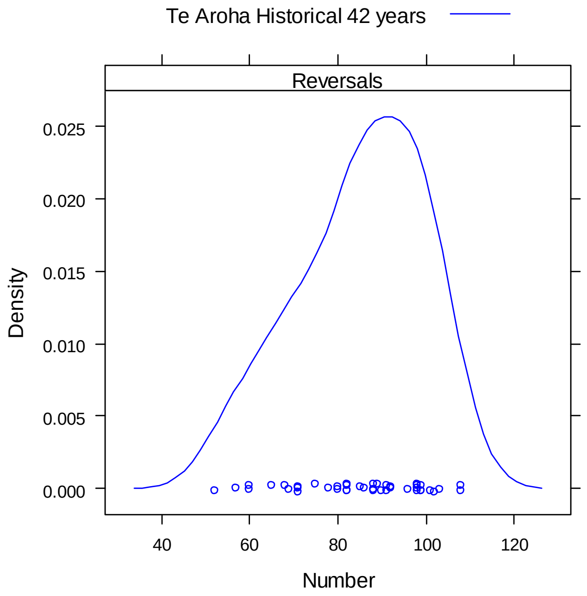

Figure 4.63: Density plot of the number of flow reversals for the Waihou River at Te Aroha.

Waihou River at Tirohia

Table 4.9 summarises the hydrologic parameters calculated for the flow record from the Waihou River at Tirohia. Figure 4.64 to Figure 4.71 illustrate the distribution of some of the key parameters that can be used for informing flow management decisions. The Tirohia gauge can be considered representative of the lower Waihou River, downstream of Te Aroha, but upstream of the tidal influence. The results for this site should be interpreted with caution due to the trends in the long-term flow records identified earlier. Trends in the data will be incorporated into the measures of variability calculated for the hydrologic parameters.

Figure 4.64 compares the median monthly flows for the Waihou River at Tirohia. Greater seasonality is again present in the monthly flows although the autumn low flows are slightly more variable than those observed at Te Aroha. The lowest median flow of 28.69 m^3 s^{-1} occurs in March. The highest median monthly flow is 45.54 m^3 s^{-1} in August.

The distribution of the mean 7-day low flow parameter is shown in Figure 4.65. The median value is 23.36 m^3 s^{-1}, which is lower than that for Te Aroha. On average, approximately 2 in 3 years will have a 7-day low flow between 93% and 124% of the median indicating a slightly higher level of inter-annual variability than observed at Te Aroha. This is also observed in the other low flow statistics (Figure 4.66).

Figure 4.67 shows the distribution of the high flow statistics. As would be expected, the variability in peak flow narrows with increasing event duration as the influence of extreme events is reduced. The median 1-day maximum flow is 136.7 m^3 s^{-1} and the median 7-day flow maximum is 107.1 m^3 s^{-1}, both of which are lower than the equivalent parameters for the Te Aroha gauge upstream. This seems an unusual result and could suggest an attenuation of the flood peak or loss of water between the two gauges.

Figure 4.68 shows the distribution of BFI over the duration of the flow record. The median BFI for the Waihou River at Tirohia is 0.62, which is similar to the Waihou River at Te Aroha (0.64).

Figure 4.69 shows the distribution of the Julian day of annual 1-day flow minima and maxima. The median Julian day of the 1-day low flow event is at the beginning of March. Similarly to the Te Aroha site, the timing of the median 1-day high flow event falls in July, and occurs in the June to August period on average 1 in every 3 years.

Figure 4.70 displays the distribution of the number of low and high flow pulses. The median number of low pulses is 10.0. The median duration of low pulses was 10.5 days, but the maximum was 366 days indicating at least one year when flow did not fall below the low pulse threshold for the whole year. The median number of high pulses was 12.0 pulses, with a median duration of 5.5 days with a maximum of 8.5. Figure 4.71 shows a density plot for the number of flow reversals. The median number of days on which reversals occur is 90.0, a similar value to the Te Aroha site.

Table 4.9: Summary of flow variability parameters for the Waihou River at Tirohia.

	Minimum	16^{th} percentile	33^{rd} percentile	Median	67^{th} percentile	84^{th} percentile	Maximum
Median flow ($m^3 s^{-1}$), Jan	21.94	25.34	26.67	29.01	31.41	37.22	51.63
Median flow ($m^3 s^{-1}$), Feb	21.77	24.22	26.22	28.88	29.93	31.89	43.40
Median flow ($m^3 s^{-1}$), Mar	22.36	24.10	25.84	28.69	30.74	32.70	60.90
Median flow ($m^3 s^{-1}$), Apr	21.97	24.60	27.45	28.95	31.68	36.52	66.68
Median flow ($m^3 s^{-1}$), May	21.76	25.75	28.49	31.14	34.91	41.55	57.67
Median flow ($m^3 s^{-1}$), Jun	25.07	30.67	33.61	38.45	43.48	52.80	69.90
Median flow ($m^3 s^{-1}$), Jul	27.42	31.06	38.05	42.74	52.45	64.35	80.88
Median flow ($m^3 s^{-1}$), Aug	27.12	33.59	41.22	45.54	53.05	61.83	78.64
Median flow ($m^3 s^{-1}$), Sep	25.95	32.30	34.66	40.17	45.23	54.38	77.41
Median flow ($m^3 s^{-1}$), Oct	24.04	28.01	34.03	36.45	41.76	49.08	66.57
Median flow ($m^3 s^{-1}$), Nov	23.28	26.12	29.23	33.15	34.32	36.52	49.40
Median flow ($m^3 s^{-1}$), Dec	22.50	25.35	29.73	31.34	34.95	38.03	73.51
1 Day Flow Mins ($m^3 s^{-1}$)	19.92	21.35	22.23	23.22	25.61	27.90	30.02
1 Day Flow Maxs ($m^3 s^{-1}$)	82.53	104.6	121.1	136.7	145.4	178.7	399.7
3 Day Flow Mins ($m^3 s^{-1}$)	19.97	21.42	22.32	23.29	26.08	28.18	30.49
3 Day Flow Maxs ($m^3 s^{-1}$)	79.56	97.82	115.7	128.8	136.8	163.8	268.0
7 Day Flow Mins ($m^3 s^{-1}$)	20.05	21.73	22.56	23.36	26.44	28.89	30.68
7 Day Flow Maxs ($m^3 s^{-1}$)	61.37	81.68	102.7	107.1	115.2	130.6	183.2
30 Day Flow Mins ($m^3 s^{-1}$)	21.82	23.17	23.77	25.20	28.47	30.11	33.23
30 Day Flow Maxs ($m^3 s^{-1}$)	43.57	54.53	63.35	72.24	76.86	84.20	100.8
90 Day Flow Mins ($m^3 s^{-1}$)	22.68	24.67	26.95	28.56	30.27	34.72	37.94
90 Day Flow Maxs ($m^3 s^{-1}$)	36.54	46.49	52.37	55.89	58.51	67.70	85.97
Base Flow Index	0.47	0.56	0.59	0.62	0.65	0.67	0.81
Julian day of min flow (Day 0 = 01 July)	121	201	228	245	274	305	341
Julian day of max flow (Day 0 = 01 January)	1	76	169	199	224	249	338
Number of low pulses	1.00	2.00	5.00	10.00	12.00	15.20	22.00
Median duration low pulses (Days)	3.00	4.70	6.00	10.50	23.40	178.3	366.0
Number of high pulses	3.00	9.40	10.20	12.00	13.00	16.00	19.00
Median duration high pulses (Days)	2.00	3.20	4.00	5.50	6.00	6.80	11.00
Number of positive differences between days	102.0	115.6	122.0	125.0	129.6	132.6	151.0
Median of positive differences between days	0.57	0.93	1.29	1.57	1.91	2.38	3.23
Number of negative differences between days	175.0	215.0	230.2	235.0	237.0	243.6	261.0
Median of negative differences between days	-1.89	-1.40	-1.20	-1.07	-0.92	-0.83	-0.54
Reversals	58.00	76.00	85.40	90.00	93.80	97.60	112.0

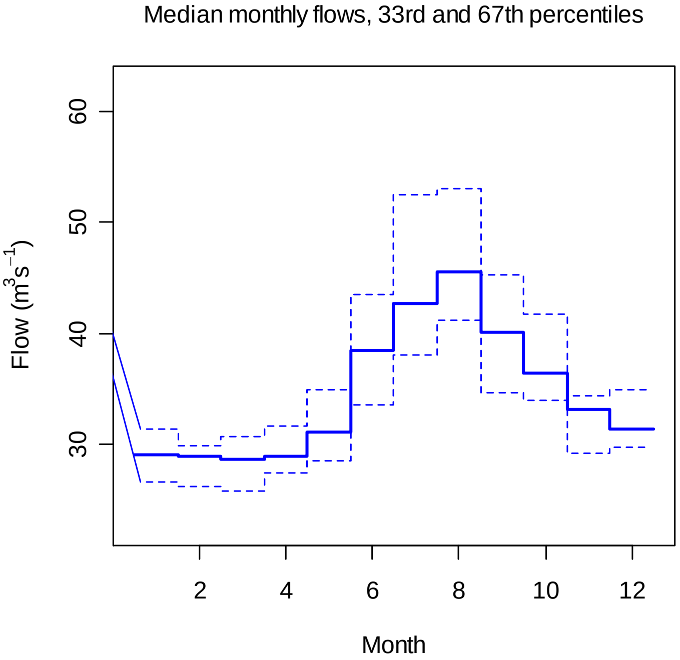

Figure 4.64: Plots of median (solid line) and 33rd and 67th percentile (dashed lines) monthly flows for the Waihou River at Tirohia.

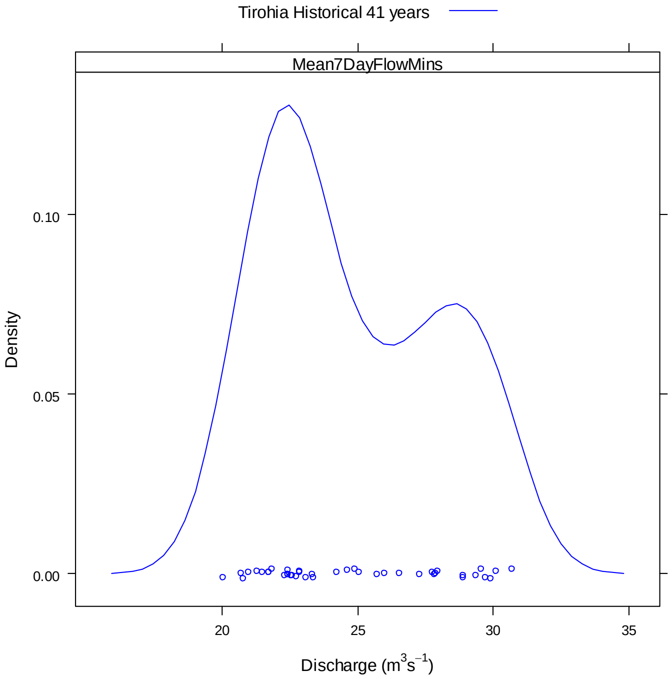

Figure 4.65: Density plot of mean 7-day flow minima for the Waihou River at Tirohia.

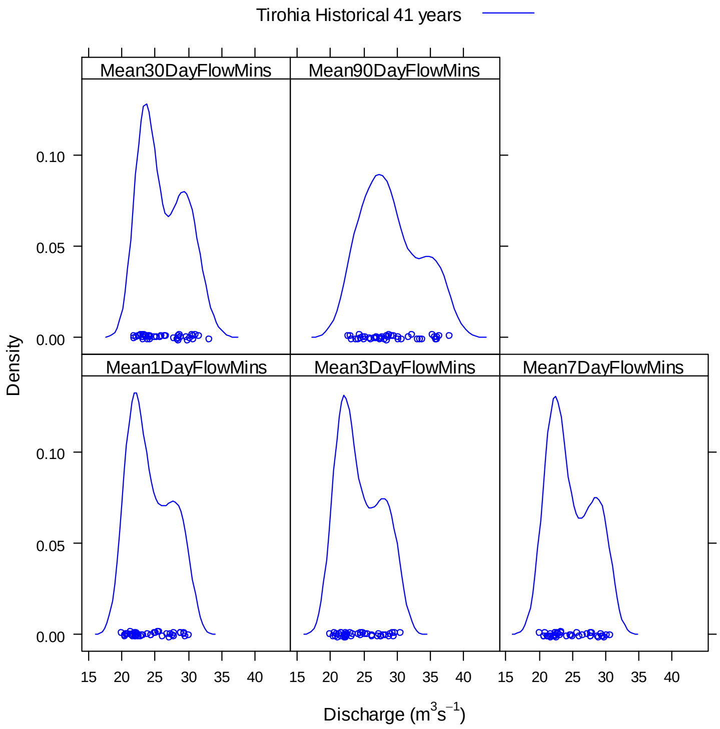

Figure 4.66: Density plots of mean flow minima for the Waihou River at Tirohia.

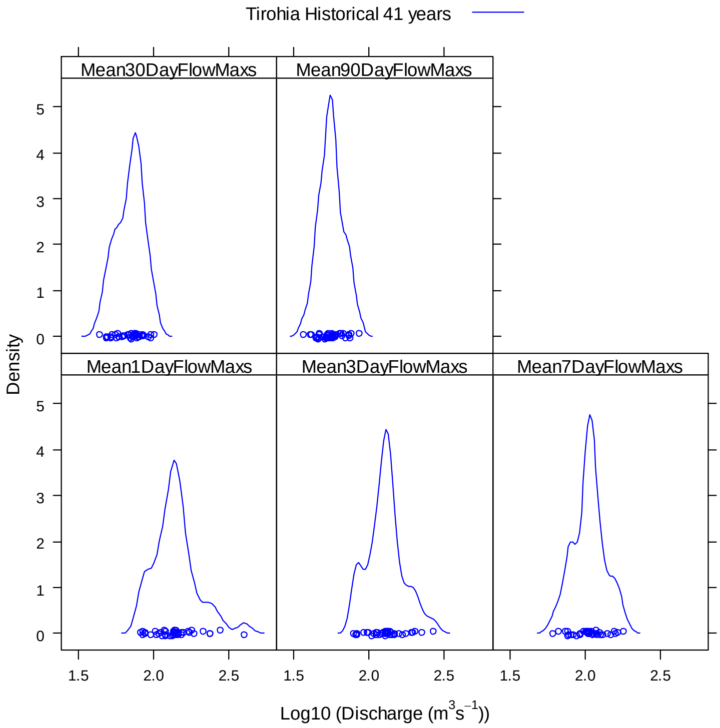

Figure 4.67: Density plots of mean flow maxima for the Waihou River at Tirohia.

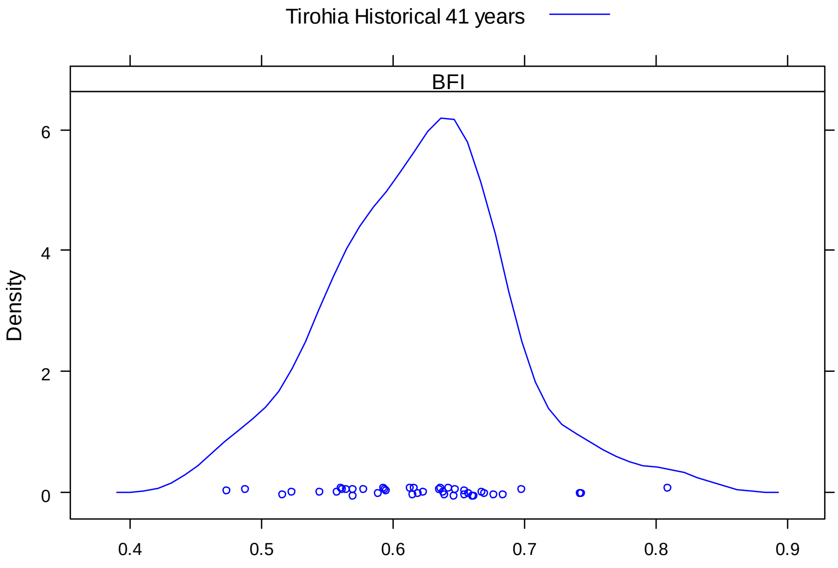

Figure 4.68: Density plot of mean base flow index for the Waihou River at Tirohia.

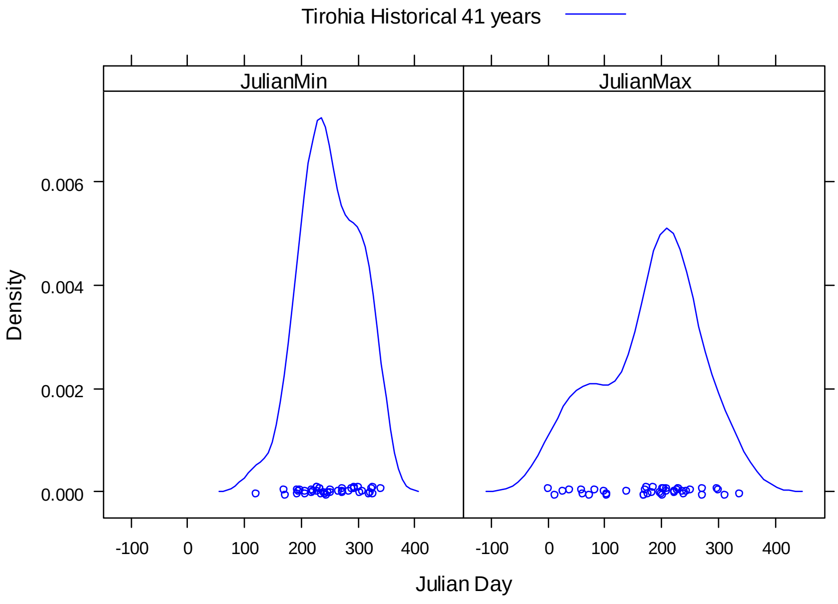

Figure 4.69: Density plots of Julian day of annual 1-day flow minimum and maximum for the Waihou River at Tirohia. Note: Water year for flow minimum starts 01 July and for flow maximum water year starts at 01 January.

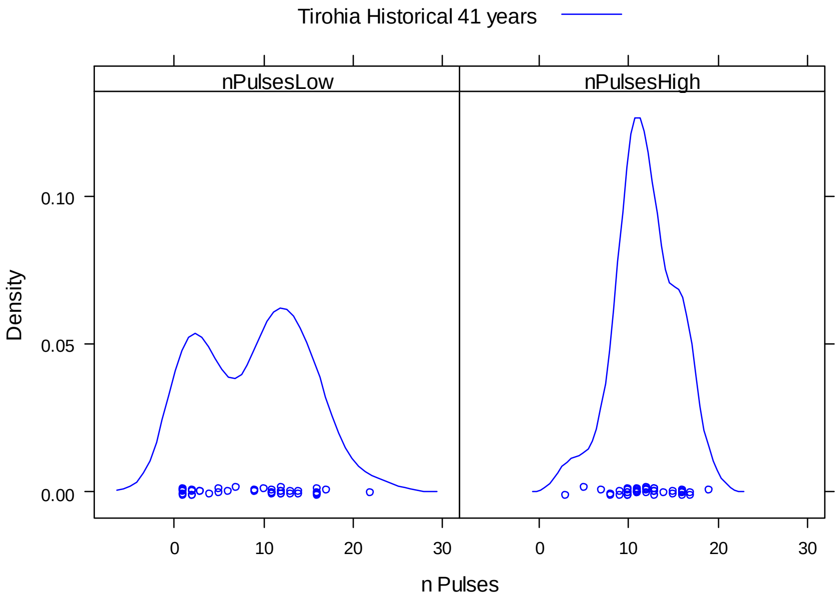

Figure 4.70: Density plots of the number of low and high flow pulses for the Waihou River at Tirohia.

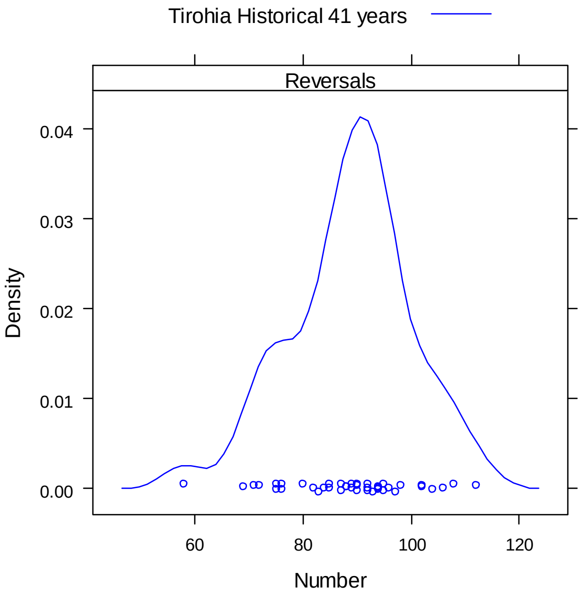

Figure 4.71: Density plot of the number of flow reversals for the Waihou River at Tirohia.

4.2 Instream ecology

4.2.1 Historical fish records

Historical data on fish communities is available in the New Zealand Freshwater Fish Database (NZFFD). These data were examined to investigate the spatial distribution of different fish species and communities throughout the Waihou catchment. The nature of the information included in the NZFFD does not make it amenable to quantitative analysis due to differences in survey methodology, sampling effort and reporting. Consequently, analysis of the historical data has been limited to consideration of species presence/absence, although this in itself can be subject to some bias due to the selectivity of some sampling methods.

Figure 4.72 displays the location of the 414 NZFFD records available for the Waihou catchment as of June 2009. Records have been colour coded according to date to indicate how recently the surveys were carried out. It can be seen that most of the surveys are restricted to the smaller tributaries that are most conducive to effective sampling. It is notable that apart from a limited area of the Mangatapu Stream, a tributary of the Oraka Stream, and the Waihou River, very few surveys have been carried out in the upper Waihou catchment upstream of Okauia. The spatial coverage of surveys in the Ohinemuri sub-catchment has also been relatively restricted in the past two decades to the Waitekauri River and the Ohinemuri River upstream of Waihi.

Table 4.10 summarises the results of the 414 records available from the NZFFD. Results are distinguished spatially between the upper Waihou catchment (upstream of Okauia), the middle Waihou catchment (Okauia to Tirohia), the lower Waihou catchment (downstream of Tirohia) and the Ohinemuri sub-catchment. These areas were defined to reflect differences in catchment characteristics (e.g., altitude and distance inland) and flow regime. In total, twenty four different fish species have been recorded from the catchment, including both native and introduced species. Both total species diversity and diversity of native species declines between the sub-catchments identified above with distance inland. This is consistent with the diadromous nature of many of New Zealand’s native fish species, with occurrence of smelt (*Retropinna retropinna*), inanga (*Galaxias maculatus*) and torrentfish (*Cheimarrichthys fosteri*), in particular, declining with distance inland. Banded kokopu (*Galaxias fasciatus*) have only been recorded in the lower Waihou area and the Ohinemuri sub-catchment. The rare species black mudfish (*Neochanna diversus*), shortjawed kokopu (*Galaxias postvectis*) and dwarf galaxias (*Galaxias divergens*) have been recorded from the catchment, although only dwarf galaxias have been recorded on more than one occasion and in recent surveys (2007).

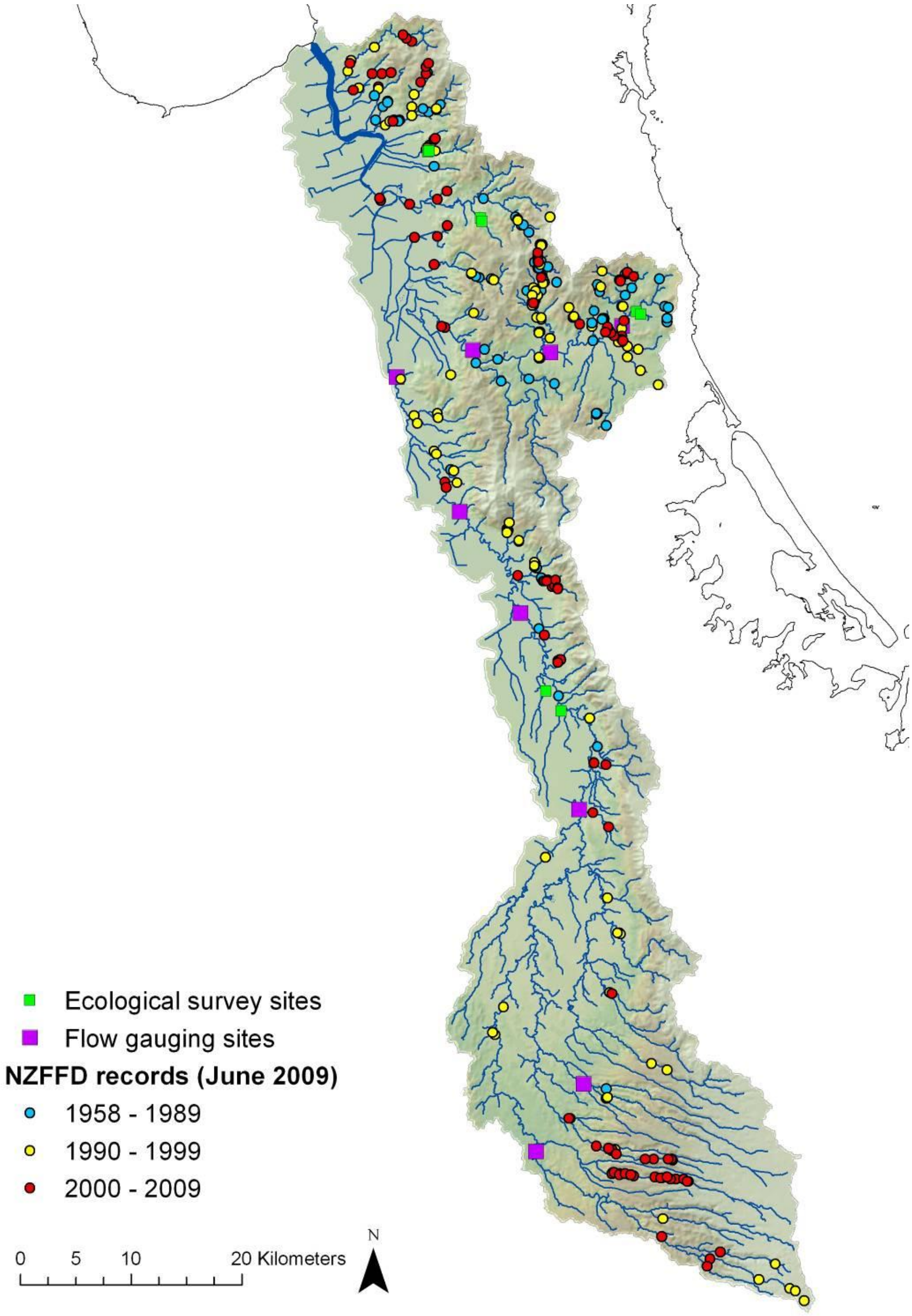

Figure 4.72: Distribution of NZFFD records in the Waihou catchment relative to flow gauges used for this study.

Table 4.10: Summary of fish records from the NZFFD for the Waihou catchment.

Scientific name	**Common name**	**Upper Waihou n=64**	**Middle Waihou n=58**	**Lower Waihou n=76**	**Ohinemuri n=216**	**Total n=414**
Oncorhynchus mykiss	Rainbow trout	19	19	17	44	99
Anguilla dieffenbachii	Longfin eel	13	28	38	141	220
Gobiomorphus cotidianus	Common bully	3	24	32	72	131
Paranephrops	Koura	37	16	25	121	199
Cheimarrichthys fosteri	Torrentfish	0	20	41	24	85
Gobiomorphus	Bullies	0	1	7	9	17
Gobiomorphus basalis	Crans bully	22	10	17	85	134
Galaxias maculatus	Inanga	1	6	9	1	17
Anguilla australis	Shortfin eel	8	18	30	102	158
Galaxias brevipinnis	Koaro	0	0	7	0	7
Retropinna retropinna	Common smelt	2	13	28	1	44
Salmo trutta	Brown trout	10	6	8	8	32
Anguilla	Unidentified eel	2	12	28	25	67
Galaxias fasciatus	Banded kokopu	0	0	10	11	21
Gobiomorphus huttoni	Redfin bully	0	4	2	3	9
Salmo	Unidentified trout	1	2	3	6	12
Galaxias postvectis	Shortjaw kokopu	0	0	0	1	1
Galaxias	Unidentified galaxiid	0	0	3	3	6
Carassius auratus	Goldfish	0	1	2	1	4
Scardinius erythrophthalmus	Rudd	0	0	0	4	4
Galaxias divergens	Dwarf galaxias	2	0	0	0	2
Gambusia affinis	Gambusia	0	3	0	0	3
Ctenopharyngodon idella	Grass carp	0	1	0	0	1
Cyprinus carpio	Koi carp	0	0	2	0	2
Perca fluviatilis	Perch	0	0	2	0	2
Tinca tinca	Tench	0	0	2	0	2
Neochanna diversus	Black mudfish	0	0	0	1	1
Ameiurus nebulosus	Catfish	0	0	1	0	1
Gobiomorphus gobioides	Giant bully	0	0	1	0	1
Total fish diversity		9	12	18	15	24
Diversity of native fish species		7	8	11	11	14

Leathwick et al. (2008a; 2008b) used statistical models to determine the main environmental conditions preferred by species of native fish in New Zealand. Environmental predictors were chosen for their functional relevance and derived from GIS information. They identified three main environmental predictors reflecting flow magnitude and variability: low flows, flow stability and the number of days of rain upstream. Low flows were represented by a fourth root transformation of the mean annual 7-day low flow, which tends to be linearly related to mean cross-sectional water velocity (Jowett, 1998) meaning that higher values typically represent higher velocity environments. Flow stability was calculated as the ratio between mean annual low flow and mean annual mean flow, with high values indicating a stable flow regime and low values, variable flows. Upstream rain days were defined as days with rainfall greater than 25 mm in the upstream catchment and can be considered as representative of the frequency of flushing flow events. Table 4.11 shows the relative contribution of these three variables for explaining the distribution of some of the main native species that occur in the Waihou catchment. It can be seen that the presence of torrentfish were identified as being more strongly influenced by flow characteristics than other species, whilst shortfin eels display a relatively low correlation with any of the flow variables.

Table 4.11: Species predictor contributions (%) for selected species found in the Waihou catchment (Source: Leathwick et al. 2008b).

Predictor	Longfin eel	Shortfin eel	Torrentfish	Banded kokopu	Smelt	Inanga	Common bully	Cran's bully
U/S rain days	5.5	2.2	5.2	4.6	4.8	2.7	4.4	5.2
Flow stability	2.8	2.3	5.2	2.6	2.4	2.9	4.1	3.2
Low flows	1.9	1.6	11.9	5.2	4.2	3.8	2.8	2.3
Total	**10.2**	**6.1**	**22.3**	**12.4**	**11.4**	**9.4**	**11.3**	**10.7**

Table 4.12 shows the mean values of the different variables for selected species across New Zealand. It can be seen that torrentfish, longfin eel, banded kokopu, inanga and common bully are typically associated with a higher frequency of upstream rain days compared to other species. Banded kokopu, inanga and common bully are also associated with relatively lower levels of flow stability, indicating these species are more likely to be found in streams with more unstable, variable flows. Both torrentfish and smelt have a relatively high mean low flow value. It is likely that for torrentfish this reflects their known preference for high velocity environments, whilst for smelt this may reflect their greater abundance in larger, lowland rivers where mean flows are higher.

Table 4.12: Mean value (calculated from a subset of 13,369 records from the NZFFD) of different predictors for selected species found in the Waihou catchment.

Predictor	Longfin eel	Shortfin eel	Torrentfish	Banded kokopu	Smelt	Inanga	Common bully	Cran's bully
U/S rain days	22.08	10.83	23.49	17.46	11.98	17.16	16.73	13.05
Flow stability	0.18	0.13	0.20	0.12	0.21	0.15	0.15	0.16
Low flows$^{0.25}$	1.10	1.11	1.38	1.01	1.65	1.10	1.25	1.04

The GIS database of environmental variables used as predictors by Leathwick et al. (2008b) was interrogated to extract the individual environmental attributes for each NZFFD record available in the Waihou catchment. Figure 4.73 to Figure 4.75 display boxplots of the different flow related variables that characterise the sites where each of the fish species have been recorded in the Waihou catchment and compares them to the national mean calculated by Leathwick et al. (2008a) (Table 4.12). Interpretation of these results should take account of limited sample sizes for some species (e.g., shortjawed kokopu (1)).

Figure 4.73 shows the distribution of the number of upstream rain days at sites where some of the main species in the Waihou catchment have been recorded. The national mean values for each species are also presented as red dots. The national mean for koaro, shortjawed kokopu and redfin bully is much higher than the range for the Waihou catchment (maximum 25.24 days) (Figure 4.76), indicating that optimal habitat for these species may not exist in the catchment. Inanga, longfin eel and banded kokopu all occur at sites closest to their respective national means. The Waihou catchment distributions of upstream rainfall days for most species overlap significantly, suggesting that the range of upstream rainfall days (c.f. number of flushing flows) in the catchment is within the tolerance limits for each species. The distributions for banded kokopu, longfin eel, Cran's bully and rainbow trout are slightly skewed towards a greater number of upstream rain days. Smelt show a propensity for sites in the Waihou catchment with a slightly lower number of upstream rain days, but higher than their national average.

There is a bi-modal distribution of flow stability present in the catchment, with very stable flows dominating in the upper catchment, and unstable flows dominant in the middle and lower sub-catchments (Figure 4.77). Because of the lower sampling intensity in the upper catchment where higher flow stability is dominant, relative to areas of lower flow stability, there is a risk of bias being present in these results.

However, in general, in the Waihou catchment banded kokopu, inanga, koaro, smelt and torrentfish were present in sites of lower flow stability, whilst brown trout showed the greatest affinity for reaches with higher flow stability (Figure 4.74). Compared to their national means, torrentfish, smelt and koaro were all found in sites in the Waihou catchment with less stable flow. Banded kokopu, and shortfin eels were found at sites in the Waihou catchment where flows were more stable than the national average for sites where these species are present (Figure 4.74).

Figure 4.75 shows how the low flow characteristics of sites in the Waihou catchment where different species were present compare to the national mean. The locations of smelt, torrentfish and common bully display the greatest deviance from their national means, but the majority of species are present at sites in the Waihou characterised by low flows less than the national average for the species. This may reflect a bias in sampling towards small first and second order streams where flows are naturally lower. Within the Waihou catchment, common bully, Cran's bully and shortfin eels display the greatest tendency towards sites with higher low flows.

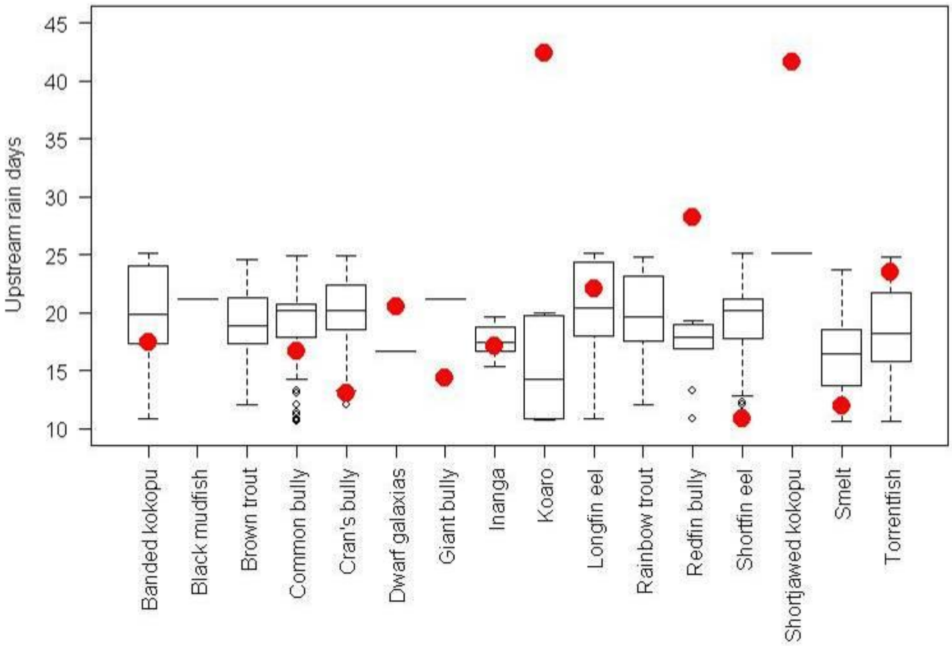

Figure 4.73: Boxplots of upstream rain days for all NZFFD records from the Waihou catchment. Red dots indicate national mean calculated from 13,369 NZFFD records (Leathwick et al. 2008a).

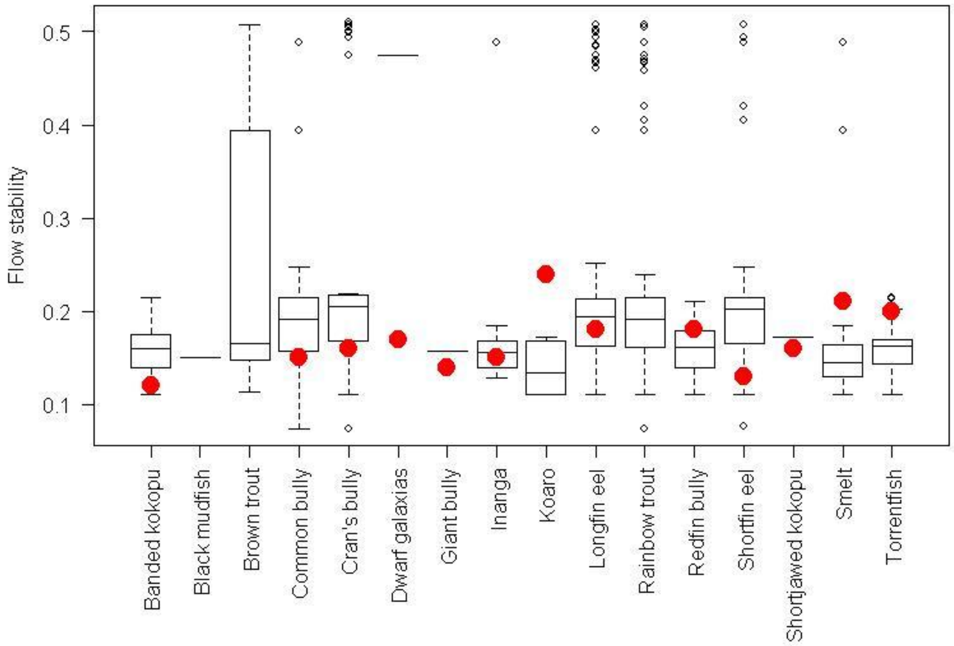

Figure 4.74: Boxplots of flow stability for all NZFFD records from the Waihou catchment. Red dots indicate national mean calculated from 13,369 NZFFD records (Leathwick et al. 2008a).

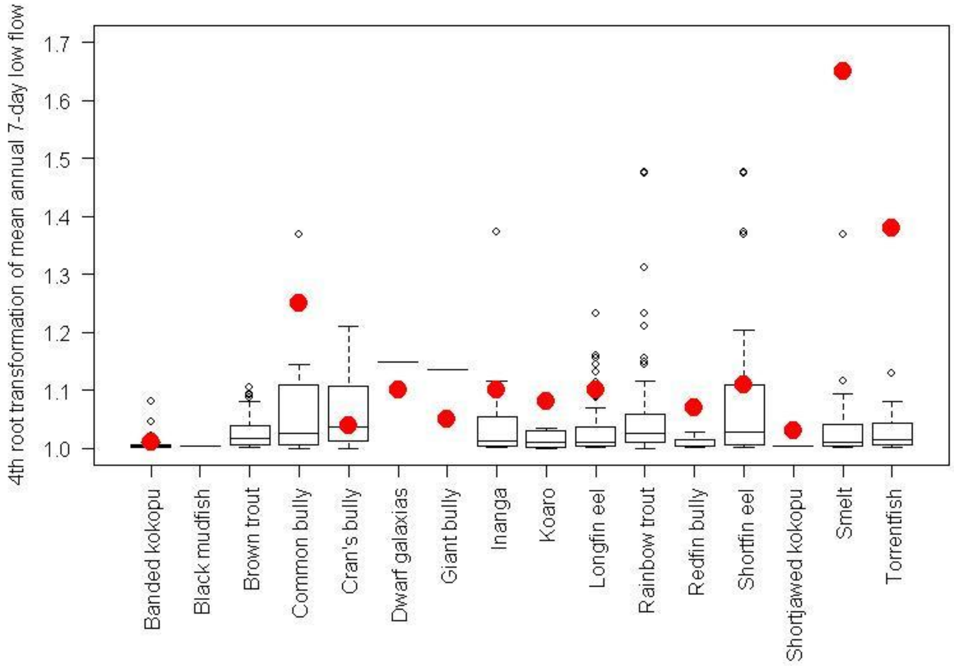

Figure 4.75: Boxplots of low flows (4th root transformation) for all NZFFD records from the Waihou catchment. Red dots indicate national mean calculated from 13,369 NZFFD records (Leathwick et al. 2008a).

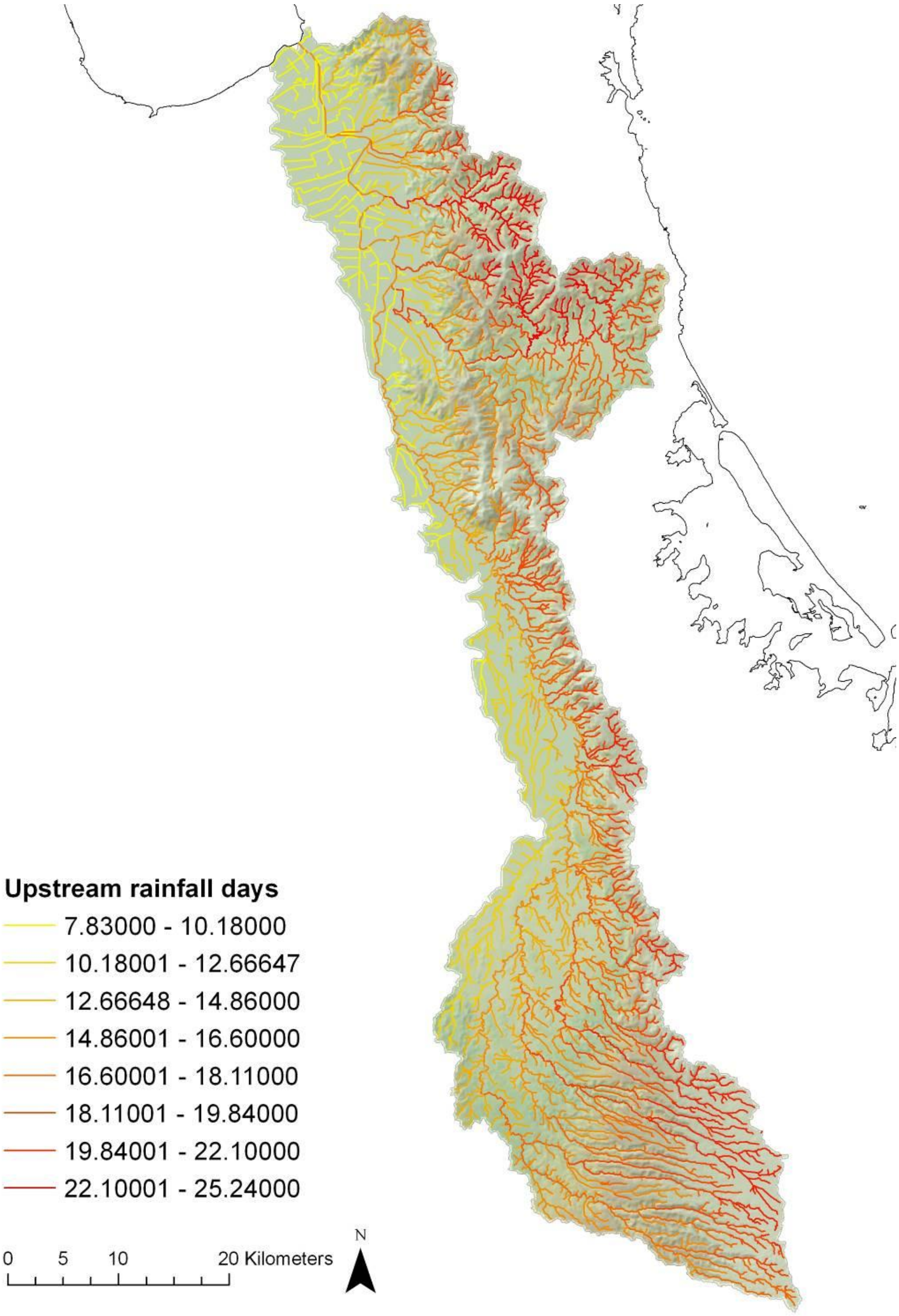

Figure 4.76: Distribution of upstream rainfall days greater than 25 mm in the Waihou catchment.

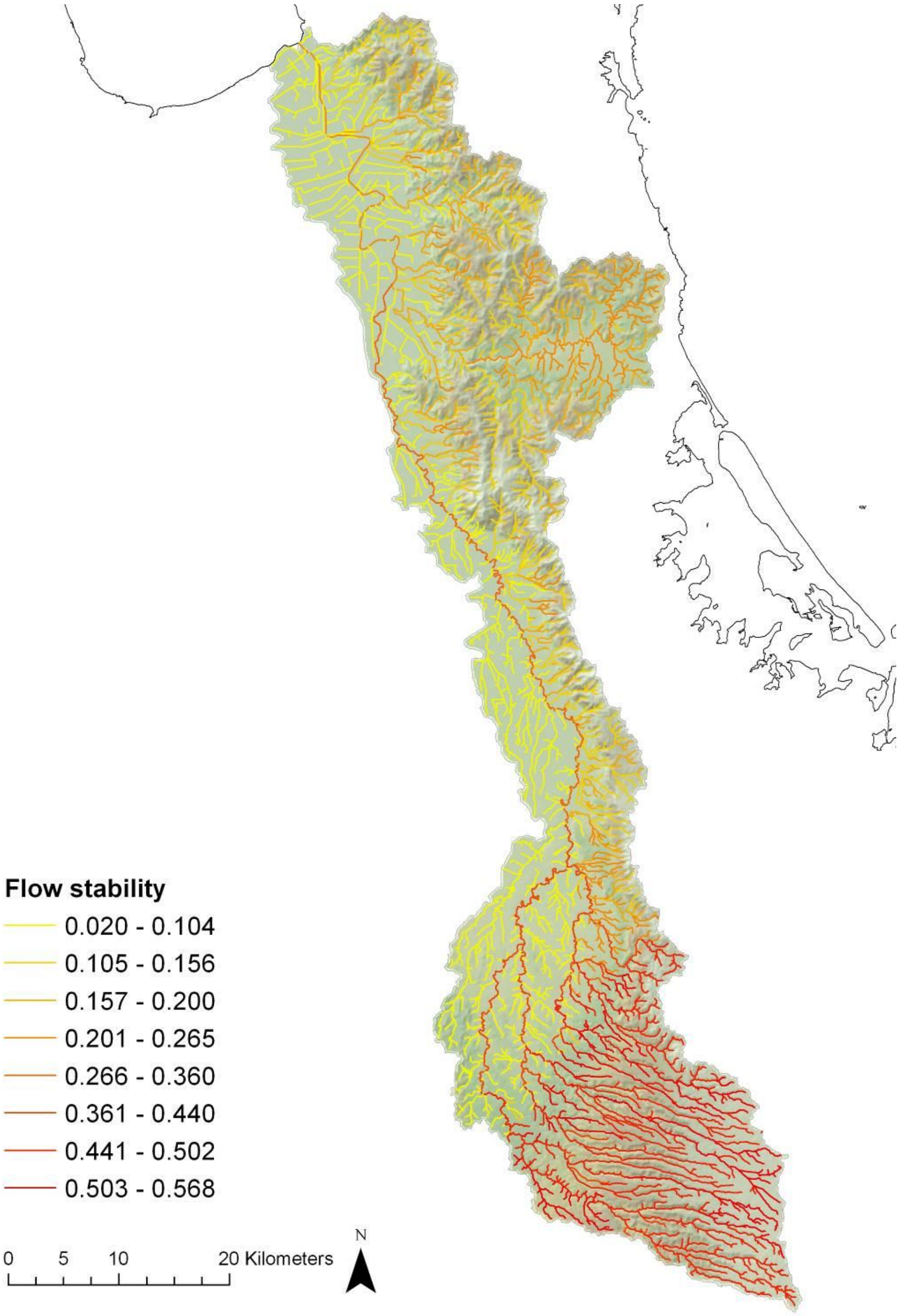

Figure 4.77: Distribution of flow stability in the Waihou catchment.

4.2.2 Current survey

The sites chosen for the current survey were selected based on their susceptibility to impacts from abstraction, scope for identifying impacts of abstraction on fish communities and their suitability as long-term monitoring sites. Two sites (Sites 1 and 2) were selected in lowland agricultural streams to fill a gap in the existing NZFFD records for the catchment. These streams are subject to multiple stressors and were identified as susceptible to future abstraction development. Plans to establish further lowland agricultural sites on the Mangawhero Stream were abandoned because macrophyte growth restricted sampling efficiency. The six remaining sites were selected as paired upstream and downstream surveys at known abstraction points to assess whether impacts on instream communities could be detected at a local scale.

Site 1 – Depression Stream

Site characteristics

Site 1 was located on the Depression Stream downstream of the Manawaru Road bridge. Mean wetted width was approximately 2 m and mean depth about 0.4 m. Substrate was dominated by silt, with a high abundance of aquatic macrophytes. Land use was pasture and the stream was not fenced off from livestock (Figure 4.78). The field assessment cover form and qualitative habitat assessment field data sheet are included in Appendix 1 for further detail.

Figure 4.78: Site 1 – Depression Stream.

Fish

Three species of fish were captured in the 150 m reach, with the full diversity captured in the first 75 m of the reach (Table 4.13). Fishing efficiency was sub-optimal due to the high abundance of instream macrophytes and it is likely that the abundance of all species is underestimated. Whilst not captured during the survey, smelt have been observed in the vicinity of the survey reach on other site visits. The size range of Cran’s bully suggested the presence of at least two year classes in the reach. The shortfin eel population was dominated by individuals less than 400 mm in length.

Table 4.13: Summary of fish captured at Site 1.

Species	Count	Relative abundance (Individuals per 100m^2)	Minimum length (mm)	Maximum length (mm)
Shortfin eel	154	46.6	60	650
Cran’s bully	12	3.6	49	80
Inanga	2	0.6	74	104
Unidentified	1	0.3	NA	NA
Koura	12	3.6	NA	NA

Macroinvertebrates

Site 1 was sampled according to MfE protocol C2 for soft-bottomed streams, with 10 replicate samples of approximately 0.3 m^2 collected. Due to the high abundance of macrophytes and dominance of run habitat, sampling effort was concentrated on these habitats. The macroinvertebrate community was dominated by the mollusc *Potamopyrgus* and diptera species. Total species richness was relatively low and only a single EPT (Ephemeroptera, Plecoptera, Trichoptera) species was identified (Table 4.14). Consequently, the MCI (Macroinvertebrate Community Index) was low at 75.0 which places it in the ‘poor’ quality class as defined by Stark and Maxted (2007). It should however be noted that the MCI scores used (Collier and Kelly, 2005) were developed for hard-bottomed streams.

Table 4.14: Macroinvertebrate parameter scores for Site 1.

Parameter	Score
Total taxa richness	11
EPT richness	1
%EPT	9.1
MCI	75.0

Macrophytes

Total macrophyte cover (MTC) in the reach was high at 70%, with a channel clogginess index (MCC) of 68.5. The community was dominated by the exotic *Glyceria maxima*, with occasional *Elodea canadensis*, *Nasturtium officinale* and the native *Nitella hookeri*. There was evidence that the banks had recently been sprayed with a herbicide, resulting in die-back of riparian vegetation.

Periphyton

Periphyton abundance was relatively high and was dominated by medium to thick brown mats. The periphyton enrichment index (PEI) for the reach is 29.0 compared to a maximum value of 90. Care should be exercised in interpreting this result because the PEI was developed for stony streams rather than silty, macrophyte dominated streams. The periphyton mat index (PMI) was 45.2, which does not exceed the recommended threshold of 60 for aesthetic or recreational purposes. Because no filamentous algae were identified in the survey cross-sections, the periphyton proliferation index (PPI) is also 45.2. Collier et al. (2006) stated that PPI values >30 were generally associated with %EPT <25% and MCI values <90, which is consistent with the macroinvertebrate community of this site (%EPT=9.1; MCI=75.0). The periphyton sliminess index (PSI) was 48.4.

Site 2 – Karengorengo Stream

Site characteristics

Site 2 was located on the Karengorengo Stream upstream of the Tower Road bridge. Mean wetted width was approximately 2.8 m and mean depth about 0.4 m. Substrate was dominated by sand, with some marginal aquatic macrophytes. Mesohabitat was dominated by runs interspersed with occasional pools. Land use was rough pasture and the stream was not fenced off from livestock (Figure 4.79). The field assessment cover form and qualitative habitat assessment field data sheet are included in Appendix 1 for further detail.

Figure 4.79: Site 2 – Karengorengo Stream.

Fish

Fish diversity in the Karengorengo Stream was greater than in the nearby Depression Stream with five species captured (Table 4.15). Eels were abundant throughout the reach and the population was again dominated by shortfins. A number of large shoals of smelt were present in the reach, generally holding in deeper runs or pools before being disturbed, at which point they would rapidly disperse. All bullies were identified as common bullies, as opposed to the Cran's bullies that were present in the adjacent Depression Stream. Koura were also present in relatively high abundance.

Table 4.15: Summary of fish captured at Site 2.

Species	**Count**	**Relative abundance (Individuals per 100m^2)**	**Minimum length (mm)**	**Maximum length (mm)**
Smelt	>475	>148.7	60	100
Shortfin eel	306	95.8	65	750
Common bully	14	4.4	29	80
Inanga	3	0.9	90	100
Longfin eel	1	0.3	650	650
Unidentified	1	0.3	NA	NA
Koura	55	17.2	NA	NA

Macroinvertebrates

Site 2 was sampled according to MfE protocol C2 for soft-bottomed streams, with 10 replicate samples of approximately 0.3 m^2 collected. A combination of macrophytes (80%) and stream edge (20%), all located in run habitats was sampled. The macroinvertebrate community was again dominated by the mollusca *Potamopyrgus*, but the number of EPT taxa present increased to 4. Total species richness remained relatively low at 13 (Table 4.16). The MCI score was increased by the presence of EPT taxa to 98.3, which places it at the top end of the 'fair' quality class as defined by Stark and Maxted (2007). Again it should be noted that the MCI scores used (Collier and Kelly, 2005) were developed for hard-bottomed streams.

Table 4.16: Macroinvertebrate parameter scores for Site 2.

Parameter	Score
Total taxa richness	13
EPT richness	4
%EPT	30.8
MCI	98.3

Macrophytes

The main species present in the reach was *Nasturtium officinale*, which grew in clumps along the stream margins. Occasional patches of *Myosotis laxa* were also observed. MTC and MCC for the reach were both 13%. Full results are presented in Appendix 1.

Periphyton

No periphyton growth was identified in the surveyed cross-sections. The dominant substrate was sandy and mobile in nature, limiting the potential for periphyton establishment.

Sites 3 & 4 – Paiakarahi Stream

Site characteristics

Site 3 and 4 were located on the Paiakarahi Stream downstream and upstream, respectively, of a public water supply abstraction. Mean wetted width for Site 3 was approximately 3 m with a mean depth of 0.2 m. Site 4 was 7 m wide and 0.2 m deep. It is suggested that this difference in wetted width is a result of an increase in gradient at Site 3 and loss of water to the abstraction. Substrate at both sites was dominated by cobble, with a greater proportion of boulders present at Site 4. Riparian vegetation was dominated by native trees at both sites (Figure 4.80 and Figure 4.81). The field assessment cover forms and qualitative habitat assessment field data sheets are included in Appendix 1 for further detail.

Figure 4.80: Site 3 – Paiakarahi Stream downstream of abstraction.

Figure 4.81: Site 4 - Paiakarahi Stream upstream of abstraction.

Fish

Species diversity at both sites was eight and consisted of the same combination of species (Table 4.17 and Table 4.18). Cran’s bullies were the most abundant species at both sites. All shortfin eels were less than 160 mm indicating successful recruitment is occurring to both reaches. Banded kokopu (Figure 4.82) were captured in both reaches including a juvenile (60 mm) at the downstream site. Smelt and inanga were present in low numbers at both sites. All the rainbow trout captured were juveniles. Whilst the rank of species has altered between the two sites, this is most likely an artefact of the relatively low abundance of species rather than a real difference between the sites. Overall, there appears to be no differences in fish community structure between the two reaches, despite a substantial reduction (-57%) in channel wetted width downstream of the abstraction. The abundance of species relative to channel size was lower in the upstream reach, but because single pass electric fishing surveys were used it is not possible to determine robustly whether this reflects a difference in population density or is an artefact of differences in sampling efficiency between the two sites.

Table 4.17: Summary of fish captured at Site 3 downstream of the abstraction.

Species	Count	Relative abundance (Individuals per 100m^2)	Minimum length (mm)	Maximum length (mm)
Cran's bully	182	33.9	41	76
Shortfin eel	11	2.0	95	150
Longfin eel	10	1.9	100	400
Torrentfish	9	1.7	45	95
Banded kokopu	4	0.7	60	170
Rainbow trout	4	0.7	80	120
Smelt	2	0.4	95	95
Inanga	2	0.4	95	95
Unidentified eel	1	0.2	NA	NA
Koura	3	0.6	NA	NA

Table 4.18: Summary of fish captured at Site 4 upstream of the abstraction.

Species	Count	Relative abundance (Individuals per 100m^2)	Minimum length (mm)	Maximum length (mm)
Cran's bully	173	18.3	42	78
Longfin eel	23	2.4	350	900
Shortfin eel	18	1.9	75	160
Torrentfish	2	0.2	45	50
Inanga	2	0.2	90	100
Banded kokopu	2	0.2	110	195
Smelt	1	0.1	80	80
Rainbow trout	1	0.1	100	100
Koura	3	0.3	NA	NA

Figure 4.82: Banded kokopu (170 mm) captured from Site 3.

Macroinvertebrates

Sites 3 and 4 were sampled according to MfE protocol C1 for hard-bottomed streams, with an area of approximately 1 m^2 sampled at each site. The full sample was collected from stony riffle areas. Total species richness was considerably higher than the previous two sites at 27 and 20 for Sites 3 and 4 respectively (Table 4.19). At Site 3 the community was dominated by ephemeroptera species, particularly *Coloburiscus humeralis*. The trichoptera *Aoteapsyche* was also present in relatively high abundance. At Site 4 the relative abundance of EPT taxa was again high, particularly the trichoptera *Pycnocentrodes*. The MCI score for both sites was high at 133.1 and 121.1 for sites 3 and 4 respectively. This places both sites into the 'Excellent' quality class as defined by Stark and Maxted (2007).

Table 4.19: Macroinvertebrate parameter scores for Sites 3 and 4.

Parameter	Site 3	Site 4
Total taxa richness	27	20
EPT richness	18	12
%EPT	66.7	60.0
MCI	133.1	121.1

Macrophytes

No macrophytes were recorded in any of the surveyed cross-sections for either reach.

Periphyton

Periphyton cover at Site 3 was primarily restricted to thin films on the cobble substrate. At Site 4 the abundance of periphyton was slightly higher and showed a slight shift to thicker mats. Table 4.20 compares the periphyton indices for the two sites, indicating a reduction in all indices downstream of the abstraction.

Table 4.20: Periphyton indices for Site 3 and Site 4.

	PEI	PPI	PSI
Site 3	32.9	0.0	6.0
Site 4	42.3	42.7	15.2

Sites 5 & 6 – Omahu Stream

Site characteristics

Sites 5 and 6 were located on the Omahu Stream downstream and upstream, respectively, of an irrigation water supply abstraction. Mean wetted width was approximately 4 m with a mean depth of 0.25 m at Site 5, and 5 m wide with a depth of 0.2 m at Site 6. Substrate at Site 5 was dominated by cobbles and habitat characterised by a pool-riffle complex. At Site 6 substrate was again dominated by cobbles, but a greater proportion of the habitat was shallow run interspersed with deeper pools. Riparian vegetation was dominated by exotic trees at both sites (Figure 4.83 and Figure 4.84). The field assessment cover forms and qualitative habitat assessment field data sheets are included in Appendix 1 for further detail.

Figure 4.83: Site 5 – Omahu Stream downstream of abstraction.

Figure 4.84: Site 6 – Omahu Stream upstream of abstraction.

Fish

Species diversity and community composition was again very similar between the two survey reaches upstream and downstream of the abstraction point. A total of seven native species and one introduced species were captured during the surveys. Shortfin eels were most abundant, followed by Cran's bullies. The majority of shortfin eels were elvers. Torrentfish from a range of year classes were present in both reaches, ranging from 35-100 mm in length. Smelt and inanga were observed in both reaches evading the current produced by the electric fishing machine and thus avoiding capture. Abundance of both these species is therefore underestimated. Banded kokopu were the only species not observed in both reaches, only being captured at the downstream site. Only juveniles (50-60 mm) were caught, all from shallow marginal gravels. This life-stage can be difficult to capture during the fishing process and thus their absence from the results of the upstream reach does not preclude their presence. The small weir that marks the top of the lower reach should not act as a barrier to the upstream movement of most species, as evidenced by the presence of inanga and smelt in the upper reach. The main difference between the two sites is a relatively greater abundance of the dominant species in the upstream site, which may reflect differences in habitat availability.

Table 4.21: Summary of fish captured at Site 5 downstream of the abstraction.

Species	Count	Relative abundance (Individuals per 100m^2)	Minimum length (mm)	Maximum length (mm)
Shortfin eel	42	6.2	70	300
Cran's bully	37	5.5	25	NA*
Torrentfish	20	2.9	35	100
Inanga	11	1.6	70	100
Longfin eel	6	0.9	120	350
Smelt	5	0.7	75	NA*
Banded kokopu	4	0.6	50	60
Brown trout	1	0.1	110	110

*No maximum length was recorded

Table 4.22: Summary of fish captured at Site 6 upstream of the abstraction.

Species	Count	Relative abundance (Individuals per 100m^2)	Minimum length (mm)	Maximum length (mm)
Shortfin eel	142	16.2	110	500
Cran's bully	80	9.1	NA	NA
Longfin eel	20	2.3	100	700
Torrentfish	17	1.9	45	100
Inanga	7	0.8	70	75
Brown trout	3	0.3	95	NA*
Smelt	2	0.2	70	70
Koura	3	0.3	NA	NA

*No maximum length was recorded

Macroinvertebrates

Sites 5 and 6 were sampled according to MfE protocol C1 for hard-bottomed streams, with an area of approximately 1 m^2 sampled at each site. The full sample was collected from stony riffle areas. Total species richness was again relatively high at 21 and 22 for Sites 5 and 6 respectively (Table 4.23). At both sites the dominant species was the mollusca *Potamopyrgus*, but %EPT was still around 50% indicating the presence of a reasonable number of EPT taxa. The MCI score for both sites was relatively high at 108.0 and 121.1 for sites 5 and 6 respectively. This places Site 5 into the 'Good' and Site 6 into the 'Excellent' quality classes as defined by Stark and Maxted (2007).

Table 4.23: Macroinvertebrate parameter scores for Sites 5 and 6.

Parameter	Site 5	Site 6
Total taxa richness	21	22
EPT richness	10	11
%EPT	47.6	50.0
MCI	108.0	121.1

Macrophytes

Instream macrophyte abundance in both survey reaches was low. At Site 5 a small patch of *Nitella hookeri* was identified in one of the cross-sections, otherwise macrophytes were restricted to the marginal emergent species *Glyceria maxima* and *Veronica agnallis-aquatica*. The macrophyte indices for each site are shown in Table 4.24.

Table 4.24: Comparison of macrophyte indices for Sites 5 and 6.

	MTC	MCC	MNC
Site 5	1.2	0.8	0.8
Site 6	0.4	0.4	0.0

Periphyton

A slightly higher abundance of periphyton was observed at Site 5 relative to Site 6. Periphyton cover was characterised by thin to medium mats on the cobble substrate, with a light brown colour. Periphyton indices are shown in Table 4.25 illustrating a relatively low level for all indices.

Table 4.25: Periphyton indices for Sites 5 and 6.

	PEI	PPI	PSI
Site 5	18.3	0.0	19.0
Site 6	10.0	0.0	2.2

Sites 7 & 8 – Unnamed tributary of the Homunga Stream

Site characteristics

Sites 7 and 8 were located on an unnamed tributary of the Homunga Stream downstream and upstream, respectively, of an irrigation water supply abstraction in the upper Ohinemuri sub-catchment. Mean wetted width was approximately 2.5 m with a mean depth of 0.6 m for Site 7 and 3 m wide and 0.5 m deep for Site 8. Substrate at Site 7 was a mix of sand and cobbles, with habitat predominantly runs. At Site 8 the substrate was more heterogeneous, but dominated by sand. Habitat was a mixture of runs, riffles and pools. Riparian vegetation was primarily recently retired vegetation, recovering following fencing (Figure 4.85 and Figure 4.86). The field assessment cover forms and qualitative habitat assessment field data sheets are included in Appendix 1 for further detail.

Figure 4.85: Site 7 – Unnamed tributary of the Homunga Stream downstream of abstraction.

Figure 4.86: Site 8 - Unnamed tributary of the Homunga Stream upstream of abstraction.

Fish

Fish species diversity was limited to four species at both sites, including the introduced rainbow trout. The other species present were common bullies and the two species of eel. The population of common bullies was dominated by juveniles and the common bully was the most abundant species in both reaches. Shortfin eels were also present at relatively high abundances in both stream reaches, particularly Site 7. Again, their population structure was dominated by smaller individuals, including a number of elvers, indicating that recruitment of shortfins is successfully occurring to this part of the upper Ohinemuri catchment. Rainbow trout were captured at a relatively low abundance at both sites, but were generally larger individuals of 300-400 mm.

Table 4.26: Summary of fish captured at Site 7 downstream of abstraction.

Species	Count	Relative abundance (Individuals per 100m^2)	Minimum length (mm)	Maximum length (mm)
Common bully	143	32.6	20	NA*
Shortfin eel	133	30.4	75	NA*
Longfin eel	5	1.1	NA	1000
Rainbow trout	2	0.5	300	NA*
Koura	80	18.3	NA	NA

*No maximum length was recorded

Table 4.27: Summary of fish captured at Site 8 upstream of abstraction.

Species	Count	Relative abundance (Individuals per 100m^2)	Minimum length (mm)	Maximum length (mm)
Common bully	92	19.7	26	72
Shortfin eel	59	12.6	100	400
Rainbow trout	3	0.6	300	400
Longfin eel	2	0.4	NA	1100
Koura	45	9.6	NA	NA

Macroinvertebrates

Sites 7 and 8 were sampled according to MfE protocol C1 for hard-bottomed streams, with an area of approximately 1 m^2 sampled at each site. The full sample was collected from stony riffle areas. Unfortunately, the invertebrate sample for Site 8 was lost and results are therefore unavailable. Total species richness for Site 7 was relatively low at only 11 species (Table 4.28). The dominant species was again the mollusca *Potamopyrgus*, but %EPT significantly reduced at 27.3% reflecting the presence of only 3 EPT taxa which were all trichoptera. The MCI score for Site 7 was only 76.0. This places the site into the 'Poor' quality class as defined by Stark and Maxted (2007).

Table 4.28: Macroinvertebrate parameter scores for Sites 7 and 8.

Parameter	Site 7	Site 8
Total taxa richness	11	-
EPT richness	3	-
%EPT	27.3	-
MCI	76.0	-

Macrophytes

Macrophyte abundance in both survey reaches was again low and limited to occasional narrow bands of *Glyceria maxima* along the channel margins. This is reflected in the low macrophyte indices for both sites (Table 4.29).

Table 4.29: Comparison of macrophyte indices for Sites 7 and 8.

	MTC	MCC	MNC
Site 7	4.0	4.0	0.0
Site 8	3.0	3.0	0.0

Periphyton

No periphyton was identified in the surveyed cross-sections at Site 7. At Site 8, the upstream site, a thin film of periphyton (mean cover of 43%) was observed on the substrate. The reason for the observed difference is unclear, but may reflect a difference in substrate type and riparian cover between the two sites. The periphyton indices for Site 8 remain low (Table 4.30).

Table 4.30: Periphyton indices for Sites 7 and 8.

	PEI	PPI	PSI
Site 7	0.0	0.0	0.0
Site 8	10.0	0.0	8.6

5. Discussion

The planning of water allocation is a key component of sustainable water management. There is a need to maintain the quality and quantity of freshwater to meet environmental, economic and social needs and values. One of the main challenges to developing allocation rules is providing for competing values; resolving the conflict between sustaining environmental values and providing for efficient water resource use. Traditionally, water allocation rules have been based on the establishment of minimum flows required to sustain selected ecological values. As pressure on water resources increases and knowledge regarding the flow requirements of aquatic ecosystems improves, it is becoming increasingly recognised that the establishment of minimum flows may be insufficient for adequate protection of water resources. As more of the water resource is taken, that which remains becomes less resilient to change and increasingly susceptible to impact.

Recognition of the inadequacy of minimum flow requirements for sustaining ecological values has been driven by evidence of changes in ecosystem structure and function following alteration of flow regimes. The fundamental basis of the new paradigm for water management is that ecological communities are adapted to cope with the range of variability in environmental conditions associated with the natural flow regime. This includes the magnitude, frequency, duration, timing and rate of change in flows. Ecosystem structure and functioning is driven by the natural dynamics of the flow regime, and organism behaviour and life histories become adapted to the natural range of variability in the environment that surrounds them. Consequently, changes towards conditions outside of the range of natural variability in flows increase stress on ecological communities and inevitably result in changes to community structure and functioning. A more holistic approach to determination of ecological flow requirements has emerged recognising the importance of all components of the flow regime, rather than just low flows.

The Range of Variability Approach (RVA), and associated Indicators of Hydrologic Alteration (IHA), is one tool that has been developed to aid definition of more holistic environmental flow rules that integrate the principles of the natural flow paradigm. Although this method has not routinely been used in New Zealand and links between hydrologic parameters and ecosystems responses have not been proven, the RVA method has been applied to the Waihou catchment to support development of flow allocation rules by Environment Waikato. A range of hydrologic parameters representing different components of the flow regime were calculated from available hydrologic data, providing information on the natural range of flow variability across the catchment. Whilst calculation of the parameters is relatively straightforward, evaluating their precise ecological significance is more challenging. The Nature

Conservancy (2007) outline some of the potential ecosystem influences associated with different parameters (Table 3.1).

Whilst the logic supporting these hypothesised links is sound, understanding of the precise mechanisms and processes that link ecological responses to specific instream flow variables is relatively poor. This has necessarily led to a precautionary approach in determining flow allocation rules that aims to maximise protection of the natural ecosystem. However, this attitude is not necessarily appropriate in all situations as sustainable consumptive use of water resources can provide significant social and economic benefits which may outweigh full protection of instream ecological values.

This study has attempted to analyse and identify some of the links between instream ecology and different components of the flow regime in the Waihou catchment. Due to the limitation of being restricted to using one-off surveys, the analysis has been limited to looking at the ecological links to ‘average’ long-term flow conditions. The analysis of ecological responses to shorter-term flow dynamics requires a greater frequency of sampling tied to the occurrence of particular hydrological events.

Leathwick et al. (2008a; 2008b) have previously identified that different aspects of flow variability/stability contribute to determining the probability of occurrence of different native fish species. Some species (e.g., giant kokopu) show a greater propensity for environments with a high range of variability and frequency of flushing flows, whilst others (e.g., shortfin eel) occur more frequently in reaches with more stable flow and lower frequency of flushing flows. The same variables were analysed for the main fish species identified in the Waihou catchment. Whilst some species were present in habitats with flow characteristics similar to the national means identified by Leathwick et al. (2008a), the distribution for some species was very different. Koaro, for example, were present in reaches in the Waihou catchment with hydrological characteristics very different from the national mean values. However, the number of sites where koaro have been recorded as present in the catchment is very low, which may reflect the unavailability of habitats with the ‘ideal’ flow environment or other habitat limitations. This highlights one of the limitations in using simple presence/absence data for this kind of analysis. It fails to distinguish between communities and environments where the species composition may be the same, but relative abundance is different. Jowett (1990) showed that the distribution of trout was related to climatic, geographical and hydrological factors, but that abundance was linked to flow variability amongst other factors. This again raises the issue of how different components of the flow regime are linked to biological response and that different flow components may determine different aspects of community structure i.e., presence/absence versus abundance.

Jowett and Biggs (2008) have recently suggested that whilst flow regimes in New Zealand differ according to climate and river type, the aquatic communities are broadly similar across these regimes. They argue that the high proportion of diadromous fish in New Zealand reduces the long-term susceptibility of fish communities to inter-annual variations in flow because recruitment is external to the catchment. This means that the effect of a large disturbance is buffered in the long-term by annual re-colonisation from outside of the effected catchment. Expanding this line of argument suggests that the non-diadromous fish species may have a greater sensitivity to the effects of flow variability. This was supported by the analysis of Leathwick et al. (2008a) which suggests that non-diadromous species may be more susceptible to the impacts of flow modification. In the Waihou catchment such species include Cran's bully, dwarf galaxias and trout.

With respect to other components of the instream ecology (i.e., macroinvertebrates and macrophytes) the effect of flow variability may be greater, and thus easier to detect, because of the limited scope for behavioural response to changing conditions. Whilst fish can rapidly move between habitats in response to small variations in hydrologic conditions, periphyton, macrophytes, and to a large degree macroinvertebrates do not have this option available to them.

Successful colonisation of macrophytes is controlled by flood frequency because macrophyte immigration and growth rates are relatively slow, and thus prolonged periods of hydrological stability are required for macrophyte propagules to arrive and develop to substantial levels of cover (Biggs, 1996; Riis and Biggs, 2003). Riis and Biggs (2003) showed that vegetation abundance and species diversity within stream reaches in New Zealand were negatively correlated with flood frequency. They proposed that significant macrophyte development was restricted to streams which experienced an average of less than 13 flood events per year (where a flood event is defined as when flow exceeded 7 times the median flow). Biggs and Close (1989) have shown that hydrological factors may be as equally important as nutrients in determining periphyton biomass. Flood events which cause elevated velocities, substratum disturbance and suspended solids abrasion can cause significant loss of periphyton biomass, depending on the magnitude of the event. Biggs (2000) suggests that flood events with a 0.5-1 year return period generally result in considerable loss of periphyton biomass. This was reflected in the results of the Waihou ecological surveys which found macrophyte abundance highest in the lower gradient, lowland streams with more stable flows and a lack of significant macrophyte growth in the more flashy streams draining the Coromandel Ranges.

Macroinvertebrate communities are also known to display responses to changes in flow conditions. Townsend et al. (1997) found evidence to support the intermediate disturbance hypothesis, with taxon richness maximised in habitats subject to an intermediate level of disturbance. Susceptibility to disturbance was related to substrate size and hydrological variability. Suren and Jowett (2006) showed that invertebrate communities changed more after floods and the degree of change was proportional to flood magnitude. They also observed that community similarity increased with increasing time since the last disturbance, suggesting that the longer stable flows lasted, the less the community would change. However, it has also been recognised that the response of different species to changes in both high and low flows varies (Dewson et al. 2007; James et al. 2009). The Waihou ecological surveys were all carried out at the end of summer following a period of relatively stable low flows, and thus the results are likely to be representative of communities at their most stable.

Within the Waihou catchment a range of flow types were identified. The upper catchment is characterised by stable flows with a high proportion of baseflow, the middle and lower Waihou are also strongly influenced by the high level of baseflow in the upper catchment, but superimposed upon this is the effects of the more flashy streams draining the Kaimai and Coromandel Ranges. The Ohinemuri sub-catchment is extremely dynamic, with a strong surface-water driven flow regime characterised by low baseflows and a high frequency of flood events. The stable flow environment of the upper catchment results in a significantly higher abundance of instream macrophytes and a greater abundance of trout. Streams with higher flow variability have a greater proportion of native fish species, including banded kokopu, and a significantly lower abundance of aquatic macrophytes. In contrast, streams draining the lowland agricultural part of the catchment showed evidence of degradation, particularly with respect to the macroinvertebrate communities. This is likely to be a response to increased nutrient content, low dissolved oxygen, increased sediment load and higher water temperatures. The effects of each of these stressors will be influenced by flow dynamics and thus flow changes may alter the impact of these effects.

It is proposed that communities in areas with stable flows are most susceptible to changes in flow regime. Communities established in stable environments are typically less well adapted to extreme variations in flow. Consequently, these environments may require a greater level of protection than streams with frequent, high levels of disturbance. There is also some evidence to suggest that non-diadromous species may be more susceptible to changes in flow variables and thus should perhaps be afforded a higher level of protection. However, as mentioned earlier, evidence also suggests that fish communities within New Zealand are fairly similar across a wide range of different flow regimes. This suggests the existence of ecological redundancy in relation to flow requirements within the fish communities, with certain components of the flow regime not important in determining fish distribution (Jowett and Biggs, 2008). The establishment of long-term ecological monitoring sites in the catchment will assist in providing the information necessary for developing appropriate metrics to assess the inter-relationships between community dynamics and flows. This will enhance capabilities for identifying and prioritising protection of different components of the flow regime and optimising the water allocation decision making process.

The exploitation of ecological redundancy is the basis of the Building Block Method (King et al. 2008) and Flow Events Method (Stewardson and Gippel, 2003) for flow allocation. These are based on the concept that some flows within the complete hydrological regime are more important than others for maintenance of the river ecosystem, and that these flows can be identified and characterised in terms of their magnitude, duration, timing and frequency. However, the amount of hydrological variation required to maintain a healthy ecosystem is poorly understood and the complexity of natural systems makes it difficult to define thresholds at which the flow regime will maintain a desired river condition. This has, for example, been shown by the significant overlap in fish distributions across a range of flow conditions in the Waihou catchment.

6. Recommendations

The evaluation of values for the determination of environmental flows is beyond the scope of this report. However, the results of the hydrological analysis can provide information to support the setting of flow allocation rules for different levels of protection. The main aim of this study was to characterise the natural range of variability in flows and this has been successfully achieved for four gauging stations. Results are also provided for a further two stations, but interpretation of the results is limited by the presence of long-term temporal trends in the flow records which are consequently integrated into the measures of flow variability. Table 4.4 to Table 4.9 summarise the calculated hydrologic parameters for each site, which can be used to inform flow allocation decisions.

Ideally, the RVA is employed when comparing natural and alternative managed flow scenarios by quantifying hydrological alteration in comparison to natural variability. This was not possible for this project as currently only historical records are available for the Waihou. However, the characterisation that has been undertaken for the Waihou establishes a baseline against which future annual flow records and alternative flow management regimes can be compared. For example, flow regimes can be derived based on different allocation rules and then compared to the baseline scenario to evaluate the degree of alteration from the natural state. This can then be used to assess the relative merit of different allocation limits in terms of their impact on different components of the flow regime and determine the appropriate allocation rules for the desired level of protection. The RVA baseline can also be used to provide context for the results of other components of the instream flow setting procedure. For example, the minimum flows derived for protection of fish habitat in the Waihou catchment (Jowett, 2008) can be placed in context of the natural range of low flows that occur (See example in Appendix 5). This allows an evaluation of their potential suitability for protection of other components of the aquatic ecosystem.

It is important to understand that there are interdependencies between the different hydrologic parameters. For example, if all water above the median 7-day low flow is abstracted, then the 7-day low flow will be within the range of natural variability but many other aspects of the flow regime (e.g., seasonal patterns, rates of change) will fall outside of the range of natural variability. To optimise protection of instream values, all components of the flow regime should be managed to match the natural range of variability, which will limit the quantity of water available for other uses. As the protection level given to instream values is lowered, then greater variation from the natural regime may become more acceptable and thus water availability for other uses is increased.

The key to utilising the results of the RVA is to adopt an adaptive management approach, whereby allocation rules can be reviewed and updated in light of monitoring results and improvements in knowledge. It is recommended that initially adaptive management approaches involve the adoption of a conservative approach aiming to optimise ecosystem protection, with a consequent relaxation as understanding of the system and community responses increases. However, this may be difficult to implement in practice because it is difficult to annul water takes that have already been granted.

The primary limitation to this analysis has been the restricted availability of hydrological records within the catchment and a lack of information which can be used to link hydrological conditions with ecological responses. An effective water resource management plan should be transparent and based on a framework of scientifically robust and defensible knowledge. It is recommended that to support the adaptive management process, a network of monitoring sites should be established across the catchment. The sites should incorporate the full range of different flow regimes identified in the catchment and should also include impacted and reference sites. Monitoring should include periphyton, macrophytes, macroinvertebrates and fish and should be carried out using standardised protocols (e.g., Collier and Kelly, 2005; Collier et al. 2006) on an annual basis. Surveys should be carried out at a similar time each year to maximise the comparability of results. Information on macroinvertebrates and fish should include quantitative information on abundance as well as species presence/absence because changes in abundance could be a precursor to future loss of species. Inclusion of a range of different ecological indicators enhances the probability of detecting changes as they may each respond to different components of the flow regime (or other factors). In addition to the ecological surveys, it is recommended that water level recorders be installed at the survey sites to provide a hydrological context to the ecological results. A number of suitable sites were identified during this study, but it is recommended that additional suitable sites be sought across a broader array of river types, particularly the upper catchment, to maximise the applicability of the results.

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8. Appendix 1 – Fish surveys

Fish collection form – Wadeable streams/rivers

Team members: Paul Franklin (NIWA) Josh Smith (NIWA) Bruno David (EW)	GPS (d/s):	E2757273	N6386560	Site:	Depression Stream			Date:	09/03/09
	GPS (u/s):	E2757201	N6386488	Not fished	Fished none collected	[✓ Fished 10 sub-reaches]	Fished 5-9 sub-reaches	Fished <5 sub-reaches	FLAG for fished/not fished

Fish sample id:	1	Total shock time (min):	43	Fishing time:	Start	10:17	Sample distance (m):	150	Wetted width (m):	A	2.1	C	1.8	E	2.8	G	2.0	I	2.2
					Finish	12:33				B	2.6	D	2.1	F	2.1	H	1.9	J	2.5

Sampling gear:	Spotlight	[✓ EFM]	Seine	Length (m) Mesh (mm)	Water visibility:	[✓ Good]	Average	Poor	Water temp. (°C):	17.5	Conductivity (µS):	241

EFM anode:	[✓ Big] Small	EFM volts (x100):	3	EFM pulse rate (Hz or pps):	65	EFM pulse width (ms):	2	Spotlight (watts):	

Species	Sub-reach tally										Total count	Sample count	Length (mm)		FLAG
	A	B	C	D	E	F	G	H	I	J			Min.	Max.	
Shortfin eel	12	10	10	12	20	18	23	15	13	20	153		60	650	
Cran's bully	1		1	1	1	4	1		3		12	8	49	80	
Koura	1		2			2	2	2	3		12				
Inanga					1	1					2		74	104	
Missed (unidentified)						1					1				
Paratya				1-10											

FLAG	Comment	FLAG	Comment
F1	Riparian zone recently sprayed, high level of organic matter instream		
F2	Fishing efficiency sub-optimal due to high macrophyte abundance		

Fish collection form – Wadeable streams/rivers

Team members: Paul Franklin (NIWA) Josh Smith (NIWA)	GPS (d/s):	E2758628	N6384754	Site: Karengorengo Stream	Date: 09/03/09
	GPS (u/s):	E2758672	N6384606		

Not fished	Fished none collected	[✓ Fished 10 sub-reaches]	Fished 5-9 sub-reaches	Fished <5 sub-reaches	FLAG for fished/not fished

Fish sample id:	2	Total shock time (min):	66	Fishing time:	Start 14:16 Finish 15:43	Sample distance (m):	150		

Wetted width (m):

A	1.8	C	1.8	E	2.1	G	2.0	I	2.8
B	2.2	D	1.8	F	1.8	H	2.9	J	2.1

Sampling gear: Spotlight [✓ EFM] Seine Length (m) / Mesh (mm)

Water visibility: [✓ Good] Average Poor

Water temp. (°C): 19

Conductivity (µS): NA

EFM anode: Big / Small

EFM volts (x100): 3

EFM pulse rate (Hz or pps): 65

EFM pulse width (ms): 2

Spotlight (watts):

Species	Sub-reach tally										Total count	Sample count	Length (mm)		FLAG
	A	B	C	D	E	F	G	H	I	J			Min.	Max.	
Shortfin eel	23	25	28	28	36	28	30	42	43	24	307		65	750	
Koura	7	4	10	2	4	5	8	1	8	6	55				
Common bully	1	1	1			2	1	4		4	14	8	29	80	
Gambusia	1			5											
Smelt	1	2		100-150		12		300-350	7		>400		60	100	
Inanga				2				1			3		90	100	
Longfin eel						1					1		650	650	
Paratya	10-100	10-100	10-100	10-100		10-100		1-10		10-100					

FLAG	Comment	FLAG	Comment
F1	Section 15-25m from d/s limit not fished because too deep, upper limit extended so		
	total reach length = 150m		

Fish collection form – Wadeable streams/rivers

Team members: Paul Franklin (NIWA) Josh Smith (NIWA) Anna Altenburger (NIWA)	GPS (d/s):	E2751347	N6429422	Site: Paiakarahi Stream (d/s)	Date: 11/03/09
	GPS (u/s):	E2751418	N6429342		

Not fished	Fished none collected	[✓ Fished 10 sub-reaches]	Fished 5-9 sub-reaches	Fished <5 sub-reaches	FLAG for fished/not fished

Fish sample id:	3	Total shock time (min):	71	Fishing time:	Start 9:10 Finish 12:20	Sample distance (m):	150

Wetted width (m):	A	3.2	C	3.7	E	3.0	G	1.8	I	5.0
	B	5.4	D	2.8	F	2.6	H	5.7	J	2.6

Sampling gear:	Spotlight	[✓ EFM]	Seine	Length (m) Mesh (mm)	Water visibility:	[✓ Good]	Average	Poor	Water temp. (°C):	16.4	Conductivity (µS):	NA

EFM anode:	[✓ Big] Small	EFM volts (x100):	4	EFM pulse rate (Hz or pps):	65	EFM pulse width (ms):	2	Spotlight (watts):	

Species	Sub-reach tally										Total count	Sample count	Length (mm)		FLAG
	A	B	C	D	E	F	G	H	I	J			Min.	Max.	
Shortfin eel			2	1	4	1	3	2		1	14		90	150	
Longfin eel	2				3		1	2	1	1	10		100	400	
Cran’s bully	20	19	19	10	14	9	13	17	34	22	177	15	41	76	
Torrentfish	1		1				1	5		1	9		45	95	
Smelt								2			2		95	95	
Koura	1					1	1				3				
Inanga				1						1	2		95	95	
Banded kokopu						2	2				4		60	170	
Rainbow trout									1	3	4		80	120	

FLAG	Comment	FLAG	Comment

Fish collection form – Wadeable streams/rivers

Team members:
Paul Franklin (NIWA)
Josh Smith (NIWA)
Anna Altenburger (NIWA)

GPS (d/s): E2751431 N6429122
GPS (u/s): E2751550 N6429031

Site: Paiakarahi Stream (u/s)

Date: 11/03/09

Not fished | Fished none collected | [✓ Fished 10 sub-reaches] | Fished 5-9 sub-reaches | Fished <5 sub-reaches | FLAG for fished/not fished

Fish sample id: 4

Total shock time (min): 102

Fishing time: Start 13:20 Finish 16:25

Sample distance (m): 142

Wetted width (m):

A	3.4	C	4.8	E	6.5	G	7.4	I	8.5
B	4.6	D	6.1	F	7.6	H	7.6	J	6.6

Sampling gear: Spotlight [✓ EFM] Seine Length (m) / Mesh (mm)

Water visibility: [✓ Good] Average Poor

Water temp. (°C):

Conductivity (µS): NA

EFM anode: [✓ Big] / Small

EFM volts (x100): 4

EFM pulse rate (Hz or pps): 65

EFM pulse width (ms): 2

Spotlight (watts):

Species	Sub-reach tally										Total count	Sample count	Length (mm)		FLAG
	A	B	C	D	E	F	G	H	I	J			Min.	Max.	
Shortfin eel	5	2	4	2	1		1	3	2	1	21		75	160	
Longfin eel	3	2	3	1	2	2	7	1	1	1	23		350	900	
Cran's bully	25	17	11	32	26	2	9	9	18	14	163		42	78	
Smelt	1										1		80	80	
Koura			1	1					1		3				
Torrentfish							2				2		45	50	
Inanga			1	1							2		90	100	
Banded Kokopu				1				1			2		110	195	
Rainbow trout							1				1		100	100	

FLAG	Comment	FLAG	Comment
F1	Skipped deep pool (8m) at base of waterfall		

Fish collection form – Wadeable streams/rivers

Team members: Paul Franklin (NIWA) Josh Smith (NIWA) Anna Altenburger (NIWA)	GPS (d/s):	E2746560	N6435409	Site:	Omahu Stream (d/s)	Date:	12/03/09
	GPS (u/s):	E2746610	N6435540				

Not fished	Fished none collected	[✓ Fished 10 sub-reaches]	Fished 5-9 sub-reaches	Fished <5 sub-reaches	FLAG for fished/not fished

Fish sample id:	5	Total shock time (min):	87	Fishing time:	Start 9:30 Finish 11:42	Sample distance (m):	150			

Wetted width (m):										
A	3.1	C	5.1	E	2.9	G	6.9	I	4.6	
B	2.9	D	5.0	F	4.2	H	5.7	J	4.5	

Sampling gear:	Spotlight	[✓ EFM]	Seine	Length (m) Mesh (mm)	Water visibility:	[✓ Good]	Average	Poor	Water temp. (°C):	NA	Conductivity (µS):	NA

EFM anode:	[✓ Big] Small	EFM volts (x100):	3	EFM pulse rate (Hz or pps):	65	EFM pulse width (ms):	2	Spotlight (watts):

Species	Sub-reach tally										Total count	Sample count	Length (mm)		FLAG
	A	B	C	D	E	F	G	H	I	J			Min.	Max.	
Shortfin eel		4	8	6	1	4	5	8	5	8	42		70	300	
Longfin eel			2			1	1	1	1		6		120	350	
Cran's bully	2	2	4	4	1	7	4	1	2	10	37		25		
Inanga			1	2		1	4	1	20	2	31		70	100	
Torrentfish		2	5	3		5				5	20		31	100	
Smelt			1			3			1		5		75		
Banded kokopu		2		1						1	4		50	60	F2
Brown trout						1				1	1		110		
Paratya	10-100	1-10	100-1000	10-100	100-1000	100-1000									

FLAG	Comment	FLAG	Comment
F1	90-115 m from d/s end not fished due to excess depth. Reach extended so full 150 m reach sampled		
F2	Juvenile BK found in v. shallow marginal areas between cobbles		

Fish collection form – Wadeable streams/rivers

Team members:
Paul Franklin (NIWA)
Josh Smith (NIWA)
Anna Altenburger (NIWA)

GPS (d/s): E2746688 N6435516
GPS (u/s): E2746806 N6435488

Site: Omahu Stream (u/s)

Date: 12/03/09

Not fished | Fished none collected | [✓ Fished 10 sub-reaches] | Fished 5-9 sub-reaches | Fished <5 sub-reaches | FLAG for fished/not fished

Fish sample id: 6

Total shock time (min): 137

Fishing time: Start 12:20 Finish 15:40

Sample distance (m): 150

Wetted width (m):

A	6.4	C	3.9	E	6.8	G	6.4	I	5.1
B	5.2	D	7.7	F	5.3	H	6.1	J	5.5

Sampling gear: Spotlight [✓ EFM] Seine Length (m) / Mesh (mm)

Water visibility: [✓ Good] Average Poor

Water temp. (°C): 18.6

Conductivity (µS): NA

EFM anode: [✓ Big] / Small

EFM volts (x100): 3

EFM pulse rate (Hz or pps): 65

EFM pulse width (ms): 2

Spotlight (watts):

Species	Sub-reach tally										Total count	Sample count	Length (mm)		FLAG
	A	B	C	D	E	F	G	H	I	J			Min.	Max.	
Cran's bully	9	12	10	3	7	13	5	1	14	7	81				F2
Shortfin eel	6	24	16	19	11	27	10	6	17	6	142		110	500	F1
Longfin eel	4	2	3	2	2	3	3		1		20		100	700	
Brown trout	1			2							3		95	95	
Torrentfish	3			10		1			3		17		45	100	
Koura	1		2								3				
Smelt		1			>50				1		50+		70	100	
Inanga		2	3		>40	2			2		50+		70	75	
Paratya	1000+	1000+													

FLAG	Comment	FLAG	Comment
F1	Most shortfins were elvers		
F2	Min & max lengths not recorded		

Fish collection form – Wadeable streams/rivers

Team members: Paul Franklin (NIWA) Josh Smith (NIWA) Anna Altenburger (NIWA)	GPS (d/s):	E2765475	N6420947	Site:	Unnamed tributary of Homunga Stream (d/s)	Date: 13/03/09
	GPS (u/s):	E2765584	N6421032			

Not fished	Fished none collected	[✓ Fished 10 sub-reaches]	Fished 5-9 sub-reaches	Fished <5 sub-reaches	FLAG for fished/not fished

Fish sample id:	7	Total shock time (min):	69	Fishing time:	Start 9:41 Finish 11:16	Sample distance (m):	150	

Wetted width (m):									
A	2.5	C	3.2	E	3.0	G	2.3	I	2.6
B	2.3	D	3.5	F	3.1	H	3.5	J	3.2

Sampling gear:	Spotlight	[✓ EFM]	Seine	Length (m) Mesh (mm)	Water visibility:	[✓ Good]	Average	Poor	Water temp. (°C):	16.1	Conductivity (µS):	NA

EFM anode:	[✓ Big] Small	EFM volts (x100):	4	EFM pulse rate (Hz or pps):	65	EFM pulse width (ms):	2	Spotlight (watts):	

Species	Sub-reach tally A	B	C	D	E	F	G	H	I	J	Total count	Sample count	Length (mm) Min.	Max.	FLAG
Shortfin eel	12	16	16	10	5	16	4	5	25	24	133		75		F3
Longfin eel			1	1		1	1	1			5			1000	F4
Common bully	5	17	16	8	8	13	16	35	40	17	175		20		F1, F2
Koura	12	7	2		1	11	5	14	14	14	80				
Rainbow trout					1	1					2		300	350	

FLAG	Comment	FLAG	Comment
F1	Majority of bullies were juveniles		
F2	No maximum length recorded		
F3	No maximum length recorded		
F4	No minimum length recorded		

Fish collection form – Wadeable streams/rivers

Team members:	GPS (d/s):	E2765847	N6420687	Site:	Unnamed tributary of Homunga Stream (u/s)	Date:	13/03/09
Paul Franklin (NIWA) Josh Smith (NIWA) Anna Altenburger (NIWA)	GPS (u/s):	E	N				

Not fished	Fished none collected	[✓ Fished 10 sub-reaches]	Fished 5-9 sub-reaches	Fished <5 sub-reaches	[✓ FLAG for fished/not fished]

Fish sample id:	8	Total shock time (min):	68	Fishing time:	Start Finish	12:05 14:10	Sample distance (m):	150

Wetted width (m):	A	3.3	C	2.4	E	2.9	G	2.4	I	3.5
	B	3.0	D	4.0	F	3.4	H	3.2	J	3.1

Sampling gear:	Spotlight	[✓ EFM]	Seine	Length (m) Mesh (mm)	Water visibility:	[✓ Good]	Average	Poor	Water temp. (°C):	NA	Conductivity (µS):	NA

EFM anode:	[✓ Big] Small	EFM volts (x100):	3	EFM pulse rate (Hz or pps):	65	EFM pulse width (ms):	2	Spotlight (watts):	

Species	Sub-reach tally										Total count	Sample count	Length (mm)		FLAG
	A	B	C	D	E	F	G	H	I	J			Min.	Max.	
Koura	2	7	2	6	2	4	5	2	10	5	45				
Shortfin eel	7	7	1	3	4	3	6	1	18	9	59		100	400	F4
Common bully	6	14	7	3	7	8	13	2	13	21	94	15	26	72	
Longfin eel						1			1		2			1100	F3
Rainbow trout					1			1		1	3		300	400	

FLAG	Comment	FLAG	Comment
F1	No upstream GPS coordinate recorded		
F2	Reach E – Large pool in middle of reach restricted fishing to margins only		
F3	No minimum length recorded		
F4	Most shortfins were elvers		
F5	5m skipped between Reach I and J because of excess depth		

9. Appendix 2 – Macroinvertebrates

Table 9.1: Full species list for macroinvertebrates. R = scan for rare taxa. Table continued over the page.

Species	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**	**Site 7**
Proportion sorted	1:12	2:12	12:12	3:12	2:12	2:12	6:12
MEGALOPTERA							
Archichauliodes diversus			46	4	8	2	
ODONATA							
Xanthocnemis zealandica	2	4					
EPHEMEROPTERA							
Acanthophlebia cruentata			1				
Ameletopsis perscitus			1				
Austroclima sepia		13	73	8	4	5	
Deleatidium sp.			60	11	4	1	
Coloburiscus humeralis			278	37	2	2	
Nesameletus			1				
Rallidens				3			
Zephlebia dentata		47	6		2		
Zephlebia versicolor		2					
Zephlebia spectablis			1				
PLECTOPTERA							
Austroperla cyrene			1			1	
Megaloptera			1				
Zelandoperla			4				
TRICHOPTERA							
Aoteapsyche			91	14	8	12	2
Beraeoptera			1	5	2	2R	
Helicopsyche						1	
Costachorema				1 R			
Hudsonema			1	1	2	1	
Hydrobiosis			7	1R		2	
Neurochorema			3	2	1		
Olinga			1				
Oxyethira				2			2
Psilochorema	1						
Pycnocentria				1		4	1
Pycnocentrodes			6	81	11	9	
Triplectides		6			2		8

Table 9.1: (cont.)

Species	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
DIPTERA							
Aphrophila			47	7	1		
Austrosimulium		1	31		4	6	30
Limonia nigrescens						1	
Chironomus zealandicus	2						
Corynoneura	1						
Cricotopus sp.	2		3	1	8	3	1
Piara							
Maoridiamesa			2				
Polypedilum	12	2			1		
Naeonella						1	
Tanypodinae				1			
Tanytarsus	1		1	5			
Tanyderidae					1		
COLEOPTERA							
Elmidae			53	23	36	12	13
MOLLUSCA							
Latia						1	
Physa		1R					
Potamopyrgus	585	238	64	23	127	165	175
HEMIPTERA							
Sigara		1R					
OLIGOCHAETA							
Oligochaeta	2				1	2	1
PLATYHELMINTHES							
Platyhelminthes	3				2		2
HIRUDINEA							
Leech							1
CRUSTACEA							
Ostracoda	1	6					
Paracalliope fluviatillis		21				1	
Paranephrops		1	2				
Paratya					2	5	

10. Appendix 3 – Macrophyte and periphyton data

Periphyton Assessment

Stream: Depression Stream		Date: 09/03/09					
Sample Number:		Located number: Site 1					
Thickness category	**Colour category**	**A**	**B**	**C**	**D**	**E**	**Mean cover**
Thin (<0.5mm) Mat/Film	NA						0
Medium mat/film (0.5-3mm thick)	Green (% cover)						0
	Light brown (% cover)		30	40	15	70	31
	Black/dark brown (% cover)		15				3
Thick (>3mm) mat/film	Green/light brown (% cover)						0
	Black/dark brown (% cover)	80			60		28
Filaments short (<2cm)	Green (% cover)						0
	Brown/Reddish (% cover)						0
Filaments long (>2cm)	Green (% cover)						0
	Brown/Reddish (% cover)						0
Submerged bryophytes	NA						0
Iron Bacteria growths	NA						0

Macrophyte recording sheet

Stream: Depression Stream | **Located number**: Site 1 | **Sample Number**: | **Date**: 09/03/09

			Vegetation cover (% wetted area)							
				Submerged plants					Emergent plants	
					Surface-reaching		Below surface			
Transect	Wetted width (m)	Channel width (m)	Total cover	Total submerged	Sub-total	Species	Sub-total	Species	Total emergent	Species
1	2.3	5	100						100	Gm
2	2.3	4	60	10			10	Nh (8) Ec (2)	50	Gm
3	2.8	5	70	5			5	Ec	65	Gm (60) Na (5)
4	2.6	5.5	70						70	Gm
5	2.2	4	50						50	Gm (45) Na (5)

Periphyton Assessment							
Stream: Karengorengo Stream		Date: 09/03/09					
Sample Number:		Located number: Site 2					
Thickness category	**Colour category**	**A**	**B**	**C**	**D**	**E**	**Mean cover**
Thin (<0.5mm) Mat/Film	NA						0
Medium mat/film (0.5-3mm thick)	Green (% cover)						0
	Light brown (% cover)						0
	Black/dark brown (% cover)						0
Thick (>3mm) mat/film	Green/light brown (% cover)						0
	Black/dark brown (% cover)						0
Filaments short (<2cm)	Green (% cover)						0
	Brown/Reddish (% cover)						0
Filaments long (>2cm)	Green (% cover)						0
	Brown/Reddish (% cover)						0
Submerged bryophytes	NA						0
Iron Bacteria growths	NA						0

Macrophyte recording sheet

Stream: Karengorengo Stream

Located number: Site 2

Sample Number:

Date: 09/03/09

			Vegetation cover (% wetted area)							
				Submerged plants					Emergent plants	
					Surface-reaching		Below surface			
Transect	Wetted width (m)	Channel width (m)	Total cover	Total submerged	Sub-total	Species	Sub-total	Species	Total emergent	Species
1	2.8	3.5	15	0					15	Na
2	3.0	4	5	0					5	Na
3	2.8	3.5	12	3	0		3	Na	9	Na (7) Ml (2)
4	2.6	3.5	30	0					30	Na
5	2.8	3	5	0					5	Na

Periphyton Assessment

Stream: Paiakarahi Stream (d/s)	Date: 11/03/09
Sample Number:	Located number: Site 3

Thickness category	Colour category	A	B	C	D	E	Mean cover
Thin (<0.5mm) Mat/Film	NA		10	10	5	5	6
Medium mat/film (0.5-3mm thick)	Green (% cover)	40					8
	Light brown (% cover)						0
	Black/dark brown (% cover)						0
Thick (>3mm) mat/film	Green/light brown (% cover)						0
	Black/dark brown (% cover)						0
Filaments short (<2cm)	Green (% cover)						0
	Brown/Reddish (% cover)						0
Filaments long (>2cm)	Green (% cover)						0
	Brown/Reddish (% cover)						0
Submerged bryophytes	NA						0
Iron Bacteria growths	NA						0

Macrophyte recording sheet

Stream: Paiakarahi Stream (d/s)
Located number: Site 3
Sample Number:
Date: 11/03/09

			Vegetation cover (% wetted area)							
				Submerged plants					Emergent plants	
					Surface-reaching		Below surface			
Transect	Wetted width (m)	Channel width (m)	Total cover	Total submerged	Sub-total	Species	Sub-total	Species	Total emergent	Species
1	3.2	15	0							
2	3.0	10	0							
3	2.8	12	0							
4	5.7	15	0							
5	1.8	10	0							

Periphyton Assessment							
Stream: Paiakarahi Stream (u/s)		Date: 11/03/09					
Sample Number:		Located number: Site 4					
Thickness category	**Colour category**	**A**	**B**	**C**	**D**	**E**	**Mean cover**
Thin (<0.5mm) Mat/Film	NA	20			15		7
Medium mat/film (0.5-3mm thick)	Green (% cover)		2	30			6.4
	Light brown (% cover)						0
	Black/dark brown (% cover)						0
Thick (>3mm) mat/film	Green/light brown (% cover)					50	10
	Black/dark brown (% cover)						0
Filaments short (<2cm)	Green (% cover)						0
	Brown/Reddish (% cover)						0
Filaments long (>2cm)	Green (% cover)						0
	Brown/Reddish (% cover)						0
Submerged bryophytes	NA						0
Iron Bacteria growths	NA						0

Macrophyte recording sheet

Stream: Paiakarahi Stream (u/s)
Located number: Site 4
Sample Number:
Date: 11/03/09

			Vegetation cover (% wetted area)							
				Submerged plants					Emergent plants	
					Surface-reaching		Below surface			
Transect	Wetted width (m)	Channel width (m)	Total cover	Total submerged	Sub-total	Species	Sub-total	Species	Total emergent	Species
1	4.6	18	0							
2	6.4	10	0							
3	7.5	15	0							
4	7.7	18	0							
5	8.5	18	0							

Periphyton Assessment							
Stream: Omahu Stream (d/s)		Date: 12/03/09					
Sample Number:		Located number: Site 5					
Thickness category	**Colour category**	**A**	**B**	**C**	**D**	**E**	**Mean cover**
Thin (<0.5mm) Mat/Film	NA	50		70		40	32
Medium mat/film (0.5-3mm thick)	Green (% cover)					5	1
	Light brown (% cover)		30		70		20
	Black/dark brown (% cover)						0
Thick (>3mm) mat/film	Green/light brown (% cover)						0
	Black/dark brown (% cover)						0
Filaments short (<2cm)	Green (% cover)						0
	Brown/Reddish (% cover)						0
Filaments long (>2cm)	Green (% cover)						0
	Brown/Reddish (% cover)						0
Submerged bryophytes	NA						0
Iron Bacteria growths	NA						0

Macrophyte recording sheet

Stream: Omahu Stream (d/s)
Located number: Site 5
Sample Number:
Date: 12/03/09

			Vegetation cover (% wetted area)							
				Submerged plants					Emergent plants	
					Surface-reaching		Below surface			
Transect	Wetted width (m)	Channel width (m)	Total cover	Total submerged	Sub-total	Species	Sub-total	Species	Total emergent	Species
1	3.1	15	0							
2	2.9	10	0							
3	5.1	10	5	4	0		4	Nh	1	Gm
4	5.0	11	1	0					1	Gm
5	2.9	16	0						0	

Periphyton Assessment

Stream: Omahu Stream (u/s)		Date: 12/03/09					
Sample Number:		Located number: Site 6					
Thickness category	**Colour category**	**A**	**B**	**C**	**D**	**E**	**Mean cover**
Thin (<0.5mm) Mat/Film	NA				30	25	11
Medium mat/film (0.5-3mm thick)	Green (% cover)						0
	Light brown (% cover)						0
	Black/dark brown (% cover)						0
Thick (>3mm) mat/film	Green/light brown (% cover)						0
	Black/dark brown (% cover)						0
Filaments short (<2cm)	Green (% cover)						0
	Brown/Reddish (% cover)						0
Filaments long (>2cm)	Green (% cover)						0
	Brown/Reddish (% cover)						0
Submerged bryophytes	NA						0
Iron Bacteria growths	NA						0

Macrophyte recording sheet

Stream: Omahu Stream (u/s) | **Located number**: Site 6 | **Sample Number**: | **Date**: 12/03/09

Transect	Wetted width (m)	Channel width (m)	Vegetation cover (% wetted area)							
				Submerged plants					Emergent plants	
					Surface-reaching		Below surface			
			Total cover	Total submerged	Sub-total	Species	Sub-total	Species	Total emergent	Species
1	6.4	12	0						0	
2	3.9	9	0						2	Ve
3	7.7	10	0						0	
4	6.8	12	0						0	
5										

Periphyton Assessment

Stream: Unnamed trib of Homunga Stream (d/s)	Date: 13/03/09
Sample Number:	Located number: Site 7

Thickness category	Colour category	A	B	C	D	E	Mean cover
Thin (<0.5mm) Mat/Film	NA						0
Medium mat/film (0.5-3mm thick)	Green (% cover)						0
	Light brown (% cover)						0
	Black/dark brown (% cover)						0
Thick (>3mm) mat/film	Green/light brown (% cover)						0
	Black/dark brown (% cover)						0
Filaments short (<2cm)	Green (% cover)						0
	Brown/Reddish (% cover)						0
Filaments long (>2cm)	Green (% cover)						0
	Brown/Reddish (% cover)						0
Submerged bryophytes	NA						0
Iron Bacteria growths	NA						0

<table>
<tr><th colspan="11">Macrophyte recording sheet</th></tr>
<tr><td colspan="3">**Stream**: Unnamed trib of Homunga Stream</td><td colspan="3">**Located number**: Site 7</td><td colspan="3">**Sample Number**:</td><td colspan="2">**Date**: 13/03/09</td></tr>
<tr><td rowspan="4">Transect</td><td rowspan="4">Wetted width (m)</td><td rowspan="4">Channel width (m)</td><td colspan="8">Vegetation cover (% wetted area)</td></tr>
<tr><td rowspan="3">Total cover</td><td colspan="5">Submerged plants</td><td colspan="2">Emergent plants</td></tr>
<tr><td rowspan="2">Total submerged</td><td colspan="2">Surface-reaching</td><td colspan="2">Below surface</td><td colspan="2"></td></tr>
<tr><td>Sub-total</td><td>Species</td><td>Sub-total</td><td>Species</td><td>Total emergent</td><td>Species</td></tr>
<tr><td>1</td><td></td><td></td><td>0</td><td></td><td></td><td></td><td></td><td></td><td>0</td><td></td></tr>
<tr><td>2</td><td></td><td></td><td>5</td><td></td><td></td><td></td><td></td><td></td><td>5</td><td>Gm</td></tr>
<tr><td>3</td><td></td><td></td><td>15</td><td></td><td></td><td></td><td></td><td></td><td>15</td><td>Gm</td></tr>
<tr><td>4</td><td></td><td></td><td>0</td><td></td><td></td><td></td><td></td><td></td><td>0</td><td></td></tr>
<tr><td>5</td><td></td><td></td><td>0</td><td></td><td></td><td></td><td></td><td></td><td>0</td><td></td></tr>
</table>

Periphyton Assessment

Stream: Unnamed trib of Homunga Stream (u/s)

Date: 13/03/09

Sample Number:

Located number: Site 8

Thickness category	Colour category	A	B	C	D	E	Mean cover
Thin (<0.5mm) Mat/Film	NA	50	50	30	20	65	0
Medium mat/film (0.5-3mm thick)	Green (% cover)						0
	Light brown (% cover)						0
	Black/dark brown (% cover)						0
Thick (>3mm) mat/film	Green/light brown (% cover)						0
	Black/dark brown (% cover)						0
Filaments short (<2cm)	Green (% cover)						0
	Brown/Reddish (% cover)						0
Filaments long (>2cm)	Green (% cover)						0
	Brown/Reddish (% cover)						0
Submerged bryophytes	NA						0
Iron Bacteria growths	NA						0

Macrophyte recording sheet

Stream: Unnamed trib. of Homunga Stream

Located number: Site 8

Sample Number:

Date: 13/03/09

			Vegetation cover (% wetted area)							
				Submerged plants					Emergent plants	
					Surface-reaching		Below surface			
Transect	Wetted width (m)	Channel width (m)	Total cover	Total submerged	Sub-total	Species	Sub-total	Species	Total emergent	Species
1	3.5	5	0							
2	3.2	5	0							
3	2.4	5	5	0					5	Gm
4	3.4	5	0							
5	2.9	5	10	0					10	Gm

11. Appendix 4 – Field assessment and habitat assessment forms

Field Assessment Cover Form
Wadeable Hard-Bottomed and Soft-Bottomed Streams

Stream name: Depression Stream		Assessor: Paul Franklin	
Site number: 1	Sample number: 1	Date: 09/03/09	Time: 12.30
GPS coordinates	Downstream:	E2757273	N6386560
	Upstream:	E2757201	N6386488

Channel & riparian features

Canopy cover:

Open	Partly shaded	Very shaded

Fencing:	Dominant riparian vegetation:	
None/ineffective	Crops	Retired vegetation
One side/partial	**Pasture**	Native shrub
Complete	Exotic trees	Native trees

Instream hydraulic conditions

Estimated or measured reach average:

Stream width (active channel): 5 m
Stream width (water): 2.1 m
Stream depth: 0.4 m
Surface velocity: 0.3 m s^{-1}

Water quality

Temperature:	17.5	°C	Conductivity:	241	µS cm^{-1}
Dissolved oxygen:	49	%	4.62	mg l^{-1}	

Turbidity:	**Clear**	Slightly turbid	Highly turbid	Stained	Other

Stream-bottom substrata

Compaction (inorganic substrata):

Assorted sizes tightly packed &/or overlapping
Moderately packed with some overlapping
Mostly a loose assortment with little overlap
No packing/loose assortment easily moved

Embeddedness:

(% gravel-boulder particles covered by fine sediment)

<5%	5-25%	26-50%	51-75%	**>75%**

% surficial inorganic substratum size composition:

Substratum	Dimension	Percentage
Bedrock	-	
Boulder	>256mm	
Cobble	>64-256mm	
Gravel	>2-64mm	
Sand	>0.06-2mm	10
Silt	0.004-0.06mm	90
Clay	<0.004mm	

Organic material (% cover)

Large wood (>10cm diameter)

<5%	5-25%	26-50%	51-75%	>75%

Coarse detritus (small wood, sticks, leaves etc. >1mm)

<5%	5-25%	**26-50%**	51-75%	>75%

Fine (<1mm) organic deposits

<5%	5-25%	**26-50%**	51-75%	>75%

Instream plant cover (% streambed area)

Filamentous algae & mats:

<5%	**5-25%**	26-50%	51-75%	>75%

Macrophytes:

<5%	5-25%	26-50%	51-75%	**>75%**

Mosses/liverworts:

<5%	5-25%	26-50%	51-75%	>75%

Habitat types sampled

(% of effort)

Stones:	%		
Wood:	%	Riffles:	%
Macrophyte: 100	%	Runs: 100	%
Edges:	%		

Number of invertebrates returned:

Koura:	Shrimps:
Crabs:	Mussels:
Other:	
Mussel type:	
Hyridella	*Cucumerunio*

Comments:

Riparian zone recently sprayed with herbicide
High organic content

Wadeable Soft-Bottomed Streams

Qualitative Habitat Assessment Field Data Sheet

Stream name: Depression Stream
Site number: 1
Sample number: 1
Assessor: Paul Franklin
Date: 09/03/09

Habitat parameter	Category																			
	Optimal					Suboptimal					Marginal					Poor				
1. Riparian vegetative zone width	• Bankside vegetation buffer >10m • Continuous & dense					• Bankside vegetation buffer is <10m • Mostly continuous					• Pathways present and/or stock • Mostly healed over					• Breaks frequent • Human activity obvious				
Left bank:	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	[✓ 5]	4	3	2	1
Right bank:	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	[✓ 5]	4	3	2	1
Mean: 5																				
2. Vegetative protection	• Bank surfaces & immediate riparian zones covered by native vegetation • Trees, under-storey shrubs or non-woody plants present • Vegetative disruption minimal					• Bank surfaces covered mainly by native vegetation • Disruption evident • Banks may be covered by exotic forestry					• Bank surfaces covered by mixture of grasses/shrubs, blackberry, willow & introduced species • Vegetation disruption obvious • Bare soil/closely cropped vegetation common					• Bank surfaces covered by grasses & shrubs • Disruption of stream bank vegetation very high • Grass heavily grazed • Significant stock damage to bank				
Left bank:	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	[✓ 4]	3	2	1
Right bank:	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	[✓ 4]	3	2	1
Mean: 4																				
3. Bank stability	• Banks stable • Erosion/bank failure absent/minimal • <5% of bank affected					• Moderately stable • Infrequent, small areas of erosion mostly healed over • 5-30% of bank eroded					• Moderately unstable • 30-60% of bank in reach has areas of erosion • High erosion potential during floods					• Unstable • Many eroded areas • 60-100% of bank has erosional scars				
Left bank:	20	19	18	17	16	15	14	13	12	[✓ 11]	10	9	8	7	6	5	4	3	2	1
Right bank:	20	19	18	17	16	15	14	13	12	[✓ 11]	10	9	8	7	6	5	4	3	2	1
Mean: 11																				
4. Channel sinuosity	• Bends increase stream length 3-4 times longer than if it was straight					• Bends increase stream length 2-3 times longer than if it was straight					• Bends increase stream length 1-2 times longer than if it was straight					• Channel straight				
Score: 13	20	19	18	17	16	15	14	[✓ 13]	12	11	10	9	8	7	6	5	4	3	2	1
5. Channel alteration	• Changes to channel/dredging absent/minimal • Stream with normal pattern					• Some changes to channel/dredging • Evidence of past channel/dredging • Recent channel/dredging not present					• Channel changes/dredging extensive • Embankments/shoring structures present on both banks • 40-80% of reach Channelized & disrupted					• Banks shored with gabion/cement • >80% of stream reach channelized or disrupted • Instream habitat altered/absent				
Score: 16	20	19	18	17	[✓ 16]	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1

Habitat parameter	Category	Habitat parameter	Category	Habitat parameter
	Optimal		Optimal	
6. Sediment deposition	- Little/no islands or point bars present - <20% of bottom affected by sediment deposition	- New increase in bar formation, mostly from gravel, sand or fine sediment - 20-50% of bottom affected - Slight deposition in pools	- Some deposition of new gravel, sand or fine sediment on old & new bars - 50-80% of bottom affected - Sediment deposits at obstructions, constrictions & bends	- Heavy deposits of fine material - Increased bar development - >80% of bottom changing frequently - Pools almost absent due to sediment deposition
Score: 8	20 19 18 17 16	15 14 13 12 11	10 9 [✓ 8] 7 6	5 4 3 2 1
7. Pool variability	- Pools evenly mixed - Large/shallow, large/deep, small/shallow, small/deep	- Majority of pools large/deep - Very few shallow pools	- Prevalence of shallow pools	- Majority of pools small/shallow
Score: 3	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 [✓ 3] 2 1
8. Abundance & diversity of habitat	- >50% substrate favourable for invertebrate colonisation & wide variety of woody debris, riffles, root mats - Snags/ submerged logs/undercut banks/cobbles provides abundant fish cover - Must not be new or transient	- 30-50% substrate favourable for invertebrate colonisation - Snags/ submerged logs/undercut banks/cobbles - Fish cover common - Moderate variety of habitat types. Can consist of some new material	- 10-30% substrate favourable for invertebrate colonisation - Fish cover patchy - 60-90% substrate easily moved by foot - Woody debris rare or may be smothered by sediment	- <10% substrate favourable for invertebrate colonisation - Fish cover rare or absent - Substrate unstable or lacking - Stable habitats lacking or limited to macrophytes
Score: 10	20 19 18 17 16	15 14 13 12 11	[✓ 10] 9 8 7 6	5 4 3 2 1
9. Periphyton	- Periphyton not evident on hand held substrates (macrophytes, wood etc.) or fine sediments	- Periphyton not visible on substrates but obvious to touch	- Periphyton visible - <20% cover of available substrates	- Periphyton obvious & prolific - >20% cover of available substrates
Score: 10	20 19 18 17 16	15 14 13 12 11	[✓ 10] 9 8 7 6	5 4 3 2 1
TOTAL SCORE: 80				

Field Assessment Cover Form
Wadeable Hard-Bottomed and Soft-Bottomed Streams

Stream name: Karengorengo Stream		Assessor: Paul Franklin	
Site number: 2	Sample number: 2	Date: 09/03/09	Time: 16:00
GPS coordinates	Downstream:	E2758628	N6384754
	Upstream:	E2758672	N6384606

Channel & riparian features

Canopy cover:

Open	Partly shaded	Very shaded

Fencing:	Dominant riparian vegetation:	
None/ineffective	Crops	Retired vegetation
One side/partial	**Pasture**	Native shrub
Complete	Exotic trees	Native trees

Instream hydraulic conditions

Estimated or measured reach average:

Stream width (active channel): 3.5
Stream width (water): 2.8
Stream depth: 0.4
Surface velocity: 0.4

Water quality

Temperature:	19	°C	Conductivity:		µS cm^{-1}
Dissolved oxygen:		%	4.9		mg l^{-1}
Turbidity:	**Clear**	Slightly turbid	Highly turbid	Stained	Other

Stream-bottom substrata

Compaction (inorganic substrata):

Assorted sizes tightly packed &/or overlapping
Moderately packed with some overlapping
Mostly a loose assortment with little overlap
No packing/loose assortment easily moved

Embeddedness:

(% gravel-boulder particles covered by fine sediment)

<5%	**5-25%**	26-50%	51-75%	>75%

% surficial inorganic substratum size composition:

Substratum	Dimension	Percentage
Bedrock	-	
Boulder	>256mm	
Cobble	>64-256mm	
Gravel	>2-64mm	
Sand	>0.06-2mm	90
Silt	0.004-0.06mm	10
Clay	<0.004mm	

Organic material (% cover)

Large wood (>10cm diameter)

<5%	5-25%	26-50%	51-75%	>75%

Coarse detritus (small wood, sticks, leaves etc. >1mm)

<5%	**5-25%**	26-50%	51-75%	>75%

Fine (<1mm) organic deposits

<5%	**5-25%**	26-50%	51-75%	>75%

Habitat types sampled

(% of effort)

Stones:	%		
Wood:	%	Riffles:	%
Macrophyte:	80 %	Runs:	100 %
Edges:	20 %		

Instream plant cover (% streambed area)

Filamentous algae & mats:

<5%	5-25%	26-50%	51-75%	>75%

Macrophytes:

<5%	**5-25%**	26-50%	51-75%	>75%

Mosses/liverworts:

<5%	5-25%	26-50%	51-75%	>75%

Number of invertebrates returned:

Koura:	Shrimps:
Crabs:	Mussels:
Other:	
Mussel type:	
Hyridella	*Cucumerunio*

Comments:

Wadeable Soft-Bottomed Streams

Qualitative Habitat Assessment Field Data Sheet

Stream name: Karengorengo Stream
Site number: 2
Sample number: 2
Assessor: Paul Franklin
Date: 09/03/09

Habitat parameter	Category Optimal	 Suboptimal	 Marginal	 Poor
1. Riparian vegetative zone width	• Bankside vegetation buffer >10m • Continuous & dense	• Bankside vegetation buffer is <10m • Mostly continuous	• Pathways present and/or stock • Mostly healed over	• Breaks frequent • Human activity obvious
Left bank:	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 [✓ 3] 2 1
Right bank:	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 [✓ 3] 2 1
Mean: 3				
2. Vegetative protection	• Bank surfaces & immediate riparian zones covered by native vegetation • Trees, under-storey shrubs or non-woody plants present • Vegetative disruption minimal	• Bank surfaces covered mainly by native vegetation • Disruption evident • Banks may be covered by exotic forestry	• Bank surfaces covered by mixture of grasses/shrubs, blackberry, willow & introduced species • Vegetation disruption obvious • Bare soil/closely cropped vegetation common	• Bank surfaces covered by grasses & shrubs • Disruption of stream bank vegetation very high • Grass heavily grazed • Significant stock damage to bank
Left bank:	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	[✓ 5] 4 3 2 1
Right bank:	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	[✓ 5] 4 3 2 1
Mean: 5				
3. Bank stability	• Banks stable • Erosion/bank failure absent/minimal • <5% of bank affected	• Moderately stable • Infrequent, small areas of erosion mostly healed over • 5-30% of bank eroded	• Moderately unstable • 30-60% of bank in reach has areas of erosion • High erosion potential during floods	• Unstable • Many eroded areas • 60-100% of bank has erosional scars
Left bank:	20 19 18 17 16	15 14 [✓ 13] 12 11	10 9 8 7 6	5 4 3 2 1
Right bank:	20 19 18 17 16	15 14 [✓ 13] 12 11	10 9 8 7 6	5 4 3 2 1
Mean: 13				
4. Channel sinuosity	• Bends increase stream length 3-4 times longer than if it was straight	• Bends increase stream length 2-3 times longer than if it was straight	• Bends increase stream length 1-2 times longer than if it was straight	• Channel straight
Score: 11	20 19 18 17 16	15 14 13 12 [✓ 11]	10 9 8 7 6	5 4 3 2 1
5. Channel alteration	• Changes to channel/dredging absent/minimal • Stream with normal pattern	• Some changes to channel/dredging • Evidence of past channel/dredging • Recent channel/dredging not present	• Channel changes/dredging extensive • Embankments/shoring structures present on both banks • 40-80% of reach Channelized & disrupted	• Banks shored with gabion/cement • >80% of stream reach channelized or disrupted • Instream habitat altered/absent
Score: 16	20 19 18 17 [✓ 16]	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1

<table>
<tr><th rowspan="2">Habitat parameter</th><th colspan="5">Category</th><th colspan="5" rowspan="2">Habitat parameter</th><th colspan="5">Category</th><th colspan="5" rowspan="2">Habitat parameter</th></tr>
<tr><th colspan="5">Optimal</th><th colspan="5">Optimal</th></tr>
<tr><td>6. Sediment deposition</td><td colspan="5">• Little/no islands or point bars present
• <20% of bottom affected by sediment deposition</td><td colspan="5">• New increase in bar formation, mostly from gravel, sand or fine sediment
• 20-50% of bottom affected
• Slight deposition in pools</td><td colspan="5">• Some deposition of new gravel, sand or fine sediment on old & new bars
• 50-80% of bottom affected
• Sediment deposits at obstructions, constrictions & bends</td><td colspan="5">• Heavy deposits of fine material
• Increased bar development
• >80% of bottom changing frequently
• Pools almost absent due to sediment deposition</td></tr>
<tr><td>Score: 14</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>7. Pool variability</td><td colspan="5">• Pools evenly mixed
• Large/shallow, large/deep, small/shallow, small/deep</td><td colspan="5">• Majority of pools large/deep
• Very few shallow pools</td><td colspan="5">• Prevalence of shallow pools</td><td colspan="5">• Majority of pools small/shallow</td></tr>
<tr><td>Score: 8</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>8. Abundance & diversity of habitat</td><td colspan="5">• >50% substrate favourable for invertebrate colonisation & wide variety of woody debris, riffles, root mats
• Snags/ submerged logs/undercut banks/cobbles provides abundant fish cover
• Must not be new or transient</td><td colspan="5">• 30-50% substrate favourable for invertebrate colonisation
• Snags/ submerged logs/undercut banks/cobbles
• Fish cover common
• Moderate variety of habitat types. Can consist of some new material</td><td colspan="5">• 10-30% substrate favourable for invertebrate colonisation
• Fish cover patchy
• 60-90% substrate easily moved by foot
• Woody debris rare or may be smothered by sediment</td><td colspan="5">• <10% substrate favourable for invertebrate colonisation
• Fish cover rare or absent
• Substrate unstable or lacking
• Stable habitats lacking or limited to macrophytes</td></tr>
<tr><td>Score: 8</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>9. Periphyton</td><td colspan="5">• Periphyton not evident on hand held substrates (macrophytes, wood etc.) or fine sediments</td><td colspan="5">• Periphyton not visible on substrates but obvious to touch</td><td colspan="5">• Periphyton visible
• <20% cover of available substrates</td><td colspan="5">• Periphyton obvious & prolific
• >20% cover of available substrates</td></tr>
<tr><td>Score: 17</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td colspan="21">TOTAL SCORE: 95</td></tr>
</table>

Field Assessment Cover Form
Wadeable Hard-Bottomed and Soft-Bottomed Streams

Stream name: Paiakarahi Stream (d/s)		Assessor: Paul Franklin	
Site number: 3	Sample number: 3	Date: 11/03/09	Time: 13:30
GPS coordinates	Downstream:	E2751347	N6429422
	Upstream:	E2751418	N6429342

Channel & riparian features

Canopy cover:

Open	**Partly shaded**	Very shaded

Fencing:	Dominant riparian vegetation:	
None/ineffective	Crops	Retired vegetation
One side/partial	Pasture	Native shrub
Complete	Exotic trees	**Native trees**

Instream hydraulic conditions

Estimated or measured reach average:

Stream width (active channel): 8 m
Stream width (water): 3 m
Stream depth: 0.2 m
Surface velocity: 0.4 m s^{-1}

Water quality

Temperature:	16.4	°C	Conductivity:		µS cm^{-1}
Dissolved oxygen:		%	9.5		mg l^{-1}
Turbidity:	**Clear**	Slightly turbid	Highly turbid	Stained	Other

Stream-bottom substrata

Compaction (inorganic substrata):

Assorted sizes tightly packed &/or overlapping
Moderately packed with some overlapping
Mostly a loose assortment with little overlap
No packing/loose assortment easily moved

Embeddedness:

(% gravel-boulder particles covered by fine sediment)

<5%	5-25%	26-50%	51-75%	>75%

% surficial inorganic substratum size composition:

Substratum	Dimension	Percentage
Bedrock	-	
Boulder	>256mm	5
Cobble	>64-256mm	85
Gravel	>2-64mm	5
Sand	>0.06-2mm	5
Silt	0.004-0.06mm	
Clay	<0.004mm	

Organic material (% cover)

Large wood (>10cm diameter)

<5%	**5-25%**	26-50%	51-75%	>75%

Coarse detritus (small wood, sticks, leaves etc. >1mm)

<5%	5-25%	26-50%	51-75%	>75%

Fine (<1mm) organic deposits

<5%	5-25%	26-50%	51-75%	>75%

Habitat types sampled

(% of effort)

Stones:	100%		
Wood:	%	Riffles:	100 %
Macrophyte:	%	Runs:	%
Edges:	%		

Instream plant cover (% streambed area)

Filamentous algae & mats:

<5%	5-25%	26-50%	51-75%	>75%

Macrophytes:

<5%	5-25%	26-50%	51-75%	>75%

Mosses/liverworts:

<5%	5-25%	26-50%	51-75%	>75%

Number of invertebrates returned:

Koura:	Shrimps:
Crabs:	Mussels:
Other:	
Mussel type:	
Hyridella	*Cucumerunio*

Comments:

Wadeable Hard-Bottomed Streams

Qualitative Habitat Assessment Field Data Sheet

Stream name: Paiakarahi Stream (d/s)

Site number: 3

Sample number: 3

Assessor: Paul Franklin

Date: 11/03/09

Habitat parameter	Category																			
	Optimal					Suboptimal					Marginal					Poor				
1. Riparian vegetative zone width	• Bankside vegetation buffer >10m • Continuous & dense					• Bankside vegetation buffer is <10m • Mostly continuous					• Pathways present and/or stock • Mostly healed over					• Breaks frequent • Human activity obvious				
Left bank:	[✓ 20]	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Right bank:	[✓ 20]	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Mean: 20																				
2. Vegetative protection	• Bank surfaces & immediate riparian zones covered by native vegetation • Trees, under-storey shrubs or non-woody plants present • Vegetative disruption minimal					• Bank surfaces covered mainly by native vegetation • Disruption evident • Banks may be covered by exotic forestry					• Bank surfaces covered by mixture of grasses/shrubs, blackberry, willow & introduced species • Vegetation disruption obvious • Bare soil/closely cropped vegetation common					• Bank surfaces covered by grasses & shrubs • Disruption of stream bank vegetation very high • Grass heavily grazed • Significant stock damage to bank				
Left bank:	[✓ 20]	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Right bank:	[✓ 20]	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Mean: 20																				
3. Bank stability	• Banks stable • Erosion/bank failure absent/minimal • <5% of bank affected					• Moderately stable • Infrequent, small areas of erosion mostly healed over • 5-30% of bank eroded					• Moderately unstable • 30-60% of bank in reach has areas of erosion • High erosion potential during floods					• Unstable • Many eroded areas • 60-100% of bank has erosional scars				
Left bank:	20	19	18	17	16	15	14	[✓ 13]	12	11	10	9	8	7	6	5	4	3	2	1
Right bank:	20	19	18	17	16	15	14	[✓ 13]	12	11	10	9	8	7	6	5	4	3	2	1
Mean: 13																				
4. Frequency of riffles	• Riffles relatively frequent • Distance between riffles divided by stream width=5-7 • Variety of habitat is key					• Occurrence of riffles infrequent • Distance between riffles divided by stream width=7-15					• Occasional riffle or run • Bottom contours provide some habitat • Distance between riffles divided by stream width=15-25					• Generally flat water, shallow riffles • Poor habitat • Distance between riffles divided by stream width=>25				
Score: 19	20	[✓ 19]	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
5. Channel alteration	• Changes to channel/dredging absent/minimal • Stream with normal pattern					• Some changes to channel/dredging • Evidence of past channel/dredging • Recent channel/dredging not present					• Channel changes/dredging extensive • Embankments/shoring structures present on both banks • 40-80% of reach channelized & disrupted					• Banks shored with gabion/cement • >80% of stream reach channelized or disrupted • Instream habitat altered/absent				
Score: 20	[✓ 20]	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1

<table>
<tr><th rowspan="2">Habitat parameter</th><th colspan="5">Category</th><th colspan="5">Habitat parameter</th><th colspan="5">Category</th><th colspan="5">Habitat parameter</th></tr>
<tr><th colspan="5">Optimal</th><th colspan="5"></th><th colspan="5">Optimal</th><th colspan="5"></th></tr>
<tr><td>6. Sediment deposition</td><td colspan="5">• Little/no islands or point bars present
• <20% of bottom affected by sediment deposition</td><td colspan="5">• New increase in bar formation, mostly from gravel, sand or fine sediment
• 20-50% of bottom affected
• Slight deposition in pools</td><td colspan="5">• Some deposition of new gravel, sand or fine sediment on old & new bars
• 50-80% of bottom affected
• Sediment deposits at obstructions, constrictions & bends</td><td colspan="5">• Heavy deposits of fine material
• Increased bar development
• >80% of bottom changing frequently
• Pools almost absent due to sediment deposition</td></tr>
<tr><td>Score: 19</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>7. Velocity/depth regimes</td><td colspan="5">• 4 velocity/depth regimes present
• Slow/deep, slow/shallow, fast/shallow, fast/deep</td><td colspan="5">• 3 0f 4 velocity/depth regimes present
• If fast/shallow is missing then score lower</td><td colspan="5">• 2 of 4 velocity/depth regimes present
• If fast/shallow or slow/shallow are missing, score low</td><td colspan="5">• Dominated by 1 velocity/depth regime
• Usually deep/slow</td></tr>
<tr><td>Score: 20</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>8. Abundance & diversity of habitat</td><td colspan="5">• >50% substrate favourable for invertebrate colonisation & wide variety of woody debris, riffles, root mats
• Snags/ submerged logs/undercut banks/cobbles provides abundant fish cover
• Must not be new or transient</td><td colspan="5">• 30-50% substrate favourable for invertebrate colonisation
• Snags/ submerged logs/undercut banks/cobbles
• Fish cover common
• Moderate variety of habitat types. Can consist of some new material</td><td colspan="5">• 10-30% substrate favourable for invertebrate colonisation
• Fish cover patchy
• 60-90% substrate easily moved by foot
• Woody debris rare or may be smothered by sediment</td><td colspan="5">• <10% substrate favourable for invertebrate colonisation
• Fish cover rare or absent
• Substrate unstable or lacking
• Stable habitats lacking or limited to macrophytes</td></tr>
<tr><td>Score: 20</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>9. Periphyton</td><td colspan="5">• Periphyton not evident on hand held stones
• Stable substrate
• Surfaces rough to touch</td><td colspan="5">• Periphyton not visible on stones
• Stable substrate
• Periphyton obvious to touch</td><td colspan="5">• Periphyton visible
• <20% cover of available substrates</td><td colspan="5">• Periphyton obvious & prolific
• >20% cover of available substrates</td></tr>
<tr><td>Score: 15</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td colspan="21">TOTAL SCORE: 166</td></tr>
</table>

Field Assessment Cover Form
Wadeable Hard-Bottomed and Soft-Bottomed Streams

Stream name: Paiakarahi Stream (u/s)		Assessor: Paul Franklin	
Site number: 4	Sample number: 4	Date: 11/03/09	Time: 16:30
GPS coordinates	Downstream:	E2751431	N6429122
	Upstream:	E2751550	N6429031

Channel & riparian features

Canopy cover:

Open **Partly shaded** Very shaded

Fencing:	Dominant riparian vegetation:	
None/ineffective	Crops	Retired vegetation
One side/partial	Pasture	Native shrub
Complete	Exotic trees	**Native trees**

Instream hydraulic conditions

Estimated or measured reach average:

Stream width (active channel): 15 m
Stream width (water): 7 m
Stream depth: 0.2 m
Surface velocity: 0.4 m s^{-1}

Water quality

Temperature:	°C		Conductivity:		µS cm^{-1}
Dissolved oxygen:	%				mg l^{-1}
Turbidity:	**Clear**	Slightly turbid	Highly turbid	Stained	Other

Stream-bottom substrata

Compaction (inorganic substrata):

Assorted sizes tightly packed &/or overlapping
Moderately packed with some overlapping
Mostly a loose assortment with little overlap
No packing/loose assortment easily moved

Embeddedness:

(% gravel-boulder particles covered by fine sediment)

<5%	5-25%	26-50%	51-75%	>75%

% surficial inorganic substratum size composition:

Substratum	Dimension	Percentage
Bedrock	-	
Boulder	>256mm	40
Cobble	>64-256mm	55
Gravel	>2-64mm	5
Sand	>0.06-2mm	
Silt	0.004-0.06mm	
Clay	<0.004mm	

Organic material (% cover)

Large wood (>10cm diameter)

<5%	5-25%	26-50%	51-75%	>75%

Coarse detritus (small wood, sticks, leaves etc. >1mm)

<5%	5-25%	26-50%	51-75%	>75%

Fine (<1mm) organic deposits

<5%	5-25%	26-50%	51-75%	>75%

Instream plant cover (% streambed area)

Filamentous algae & mats:

<5%	5-25%	26-50%	51-75%	>75%

Macrophytes:

<5%	5-25%	26-50%	51-75%	>75%

Mosses/liverworts:

<5%	5-25%	26-50%	51-75%	>75%

Habitat types sampled

(% of effort)

Stones:	100%		
Wood:	%	Riffles:	100 %
Macrophyte:	%	Runs:	%
Edges:	%		

Number of invertebrates returned:

Koura:	Shrimps:
Crabs:	Mussels:
Other:	
Mussel type:	
Hyridella	*Cucumerunio*

Comments:

Wadeable Hard-Bottomed Streams

Qualitative Habitat Assessment Field Data Sheet

Stream name: Paiakarahi Stream (u/s)
Site number: 4
Sample number: 4
Assessor: Josh Smith
Date: 11/03/09

Habitat parameter	Category																			
	Optimal					Suboptimal					Marginal					Poor				
1. Riparian vegetative zone width	• Bankside vegetation buffer >10m • Continuous & dense					• Bankside vegetation buffer is <10m • Mostly continuous					• Pathways present and/or stock • Mostly healed over					• Breaks frequent • Human activity obvious				
Left bank:	20	19	[✓ 18]	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Right bank:	20	19	[✓ 18]	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Mean: 18																				
2. Vegetative protection	• Bank surfaces & immediate riparian zones covered by native vegetation • Trees, under-storey shrubs or non-woody plants present • Vegetative disruption minimal					• Bank surfaces covered mainly by native vegetation • Disruption evident • Banks may be covered by exotic forestry					• Bank surfaces covered by mixture of grasses/shrubs, blackberry, willow & introduced species • Vegetation disruption obvious • Bare soil/closely cropped vegetation common					• Bank surfaces covered by grasses & shrubs • Disruption of stream bank vegetation very high • Grass heavily grazed • Significant stock damage to bank				
Left bank:	20	19	18	[✓ 17]	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Right bank:	20	19	18	[✓ 17]	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Mean: 17																				
3. Bank stability	• Banks stable • Erosion/bank failure absent/minimal • <5% of bank affected					• Moderately stable • Infrequent, small areas of erosion mostly healed over • 5-30% of bank eroded					• Moderately unstable • 30-60% of bank in reach has areas of erosion • High erosion potential during floods					• Unstable • Many eroded areas • 60-100% of bank has erosional scars				
Left bank:	20	19	18	17	16	15	14	[✓ 13]	12	11	10	9	8	7	6	5	4	3	2	1
Right bank:	20	19	18	17	16	15	14	[✓ 13]	12	11	10	9	8	7	6	5	4	3	2	1
Mean: 13																				
4. Frequency of riffles	• Riffles relatively frequent • Distance between riffles divided by stream width=5-7 • Variety of habitat is key					• Occurrence of riffles infrequent • Distance between riffles divided by stream width=7-15					• Occasional riffle or run • Bottom contours provide some habitat • Distance between riffles divided by stream width=15-25					• Generally flat water, shallow riffles • Poor habitat • Distance between riffles divided by stream width=>25				
Score: 19	20	[✓ 19]	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
5. Channel alteration	• Changes to channel/dredging absent/minimal • Stream with normal pattern					• Some changes to channel/dredging • Evidence of past channel/dredging • Recent channel/dredging not present					• Channel changes/dredging extensive • Embankments/shoring structures present on both banks • 40-80% of reach channelized & disrupted					• Banks shored with gabion/cement • >80% of stream reach channelized or disrupted • Instream habitat altered/absent				
Score: 17	20	19	18	[✓ 17]	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1

<table>
<tr><th rowspan="2">Habitat parameter</th><th colspan="5">Category</th><th colspan="5" rowspan="2">Habitat parameter</th><th colspan="5">Category</th><th colspan="5" rowspan="2">Habitat parameter</th></tr>
<tr><th colspan="5">Optimal</th><th colspan="5">Optimal</th></tr>
<tr><td>6. Sediment deposition</td><td colspan="5">• Little/no islands or point bars present
• <20% of bottom affected by sediment deposition</td><td colspan="5">• New increase in bar formation, mostly from gravel, sand or fine sediment
• 20-50% of bottom affected
• Slight deposition in pools</td><td colspan="5">• Some deposition of new gravel, sand or fine sediment on old & new bars
• 50-80% of bottom affected
• Sediment deposits at obstructions, constrictions & bends</td><td colspan="5">• Heavy deposits of fine material
• Increased bar development
• >80% of bottom changing frequently
• Pools almost absent due to sediment deposition</td></tr>
<tr><td>Score: 19</td><td>20</td><td>[✓ 19]</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>7. Velocity/depth regimes</td><td colspan="5">• 4 velocity/depth regimes present
• Slow/deep, slow/shallow, fast/shallow, fast/deep</td><td colspan="5">• 3 0f 4 velocity/depth regimes present
• If fast/shallow is missing then score lower</td><td colspan="5">• 2 of 4 velocity/depth regimes present
• If fast/shallow or slow/shallow are missing, score low</td><td colspan="5">• Dominated by 1 velocity/depth regime
• Usually deep/slow</td></tr>
<tr><td>Score: 17</td><td>20</td><td>19</td><td>18</td><td>[✓ 17]</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>8. Abundance & diversity of habitat</td><td colspan="5">• >50% substrate favourable for invertebrate colonisation & wide variety of woody debris, riffles, root mats
• Snags/ submerged logs/undercut banks/cobbles provides abundant fish cover
• Must not be new or transient</td><td colspan="5">• 30-50% substrate favourable for invertebrate colonisation
• Snags/ submerged logs/undercut banks/cobbles
• Fish cover common
• Moderate variety of habitat types. Can consist of some new material</td><td colspan="5">• 10-30% substrate favourable for invertebrate colonisation
• Fish cover patchy
• 60-90% substrate easily moved by foot
• Woody debris rare or may be smothered by sediment</td><td colspan="5">• <10% substrate favourable for invertebrate colonisation
• Fish cover rare or absent
• Substrate unstable or lacking
• Stable habitats lacking or limited to macrophytes</td></tr>
<tr><td>Score: 16</td><td>20</td><td>19</td><td>18</td><td>17</td><td>[✓ 16]</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>9. Periphyton</td><td colspan="5">• Periphyton not evident on hand held stones
• Stable substrate
• Surfaces rough to touch</td><td colspan="5">• Periphyton not visible on stones
• Stable substrate
• Periphyton obvious to touch</td><td colspan="5">• Periphyton visible
• <20% cover of available substrates</td><td colspan="5">• Periphyton obvious & prolific
• >20% cover of available substrates</td></tr>
<tr><td>Score: 10</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>[✓ 10]</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td colspan="21">TOTAL SCORE: 146</td></tr>
</table>

Field Assessment Cover Form
Wadeable Hard-Bottomed and Soft-Bottomed Streams

Stream name: Omahu Stream (d/s)		Assessor: Paul Franklin	
Site number: 5	Sample number: 5	Date: 12/03/09	Time: 12:30
GPS coordinates	Downstream:	E2746560	N6435409
	Upstream:	E2746610	N6435540

Channel & riparian features

Canopy cover:

Open	**Partly shaded**	Very shaded

Fencing:	Dominant riparian vegetation:	
None/ineffective	Crops	Retired vegetation
One side/partial	Pasture	Native shrub
Complete	**Exotic trees**	Native trees

Instream hydraulic conditions

Estimated or measured reach average:

Stream width (active channel): 12 m
Stream width (water): 4 m
Stream depth: 0.25 m
Surface velocity: 0.3 m s^{-1}

Water quality

Temperature:	°C	Conductivity:	µS cm^{-1}
Dissolved oxygen:	%		mg l^{-1}

Turbidity:	**Clear**	Slightly turbid	Highly turbid	Stained	Other

Stream-bottom substrata

Compaction (inorganic substrata):

Assorted sizes tightly packed &/or overlapping
Moderately packed with some overlapping
Mostly a loose assortment with little overlap
No packing/loose assortment easily moved

Embeddedness:
(% gravel-boulder particles covered by fine sediment)

<5%	5-25%	26-50%	51-75%	>75%

% surficial inorganic substratum size composition:

Substratum	Dimension	Percentage
Bedrock	-	
Boulder	>256mm	
Cobble	>64-256mm	90
Gravel	>2-64mm	
Sand	>0.06-2mm	10
Silt	0.004-0.06mm	
Clay	<0.004mm	

Organic material (% cover)

Large wood (>10cm diameter)	**<5%**	5-25%	26-50%	51-75%	>75%
Coarse detritus (small wood, sticks, leaves etc. >1mm)	**<5%**	5-25%	26-50%	51-75%	>75%
Fine (<1mm) organic deposits	**<5%**	5-25%	26-50%	51-75%	>75%

Instream plant cover (% streambed area)

Filamentous algae & mats:	**<5%**	5-25%	26-50%	51-75%	>75%
Macrophytes:	**<5%**	5-25%	26-50%	51-75%	>75%
Mosses/liverworts:	**<5%**	5-25%	26-50%	51-75%	>75%

Habitat types sampled
(% of effort)

Stones:	100%		
Wood:	%	Riffles:	100 %
Macrophyte:	%	Runs:	%
Edges:	%		

Number of invertebrates returned:

Koura:	Shrimps:
Crabs:	Mussels:
Other:	
Mussel type:	
Hyridella	*Cucumerunio*

Comments:

Wadeable Hard-Bottomed Streams

Qualitative Habitat Assessment Field Data Sheet

Stream name: Omahu Stream (d/s)
Site number: 5

Sample number: 5
Assessor: Paul Franklin
Date: 12/03/09

Habitat parameter	Category																			
	Optimal					Suboptimal					Marginal					Poor				
1. Riparian vegetative zone width	Bankside vegetation buffer >10m Continuous & dense					Bankside vegetation buffer is <10m Mostly continuous					Pathways present and/or stock Mostly healed over					Breaks frequent Human activity obvious				
Left bank:	20	19	18	17	16	15	14	13	12	[✓ 11]	10	9	8	7	6	5	4	3	2	1
Right bank:	20	19	18	17	16	15	14	13	12	[✓ 11]	10	9	8	7	6	5	4	3	2	1
Mean: 11																				
2. Vegetative protection	Bank surfaces & immediate riparian zones covered by native vegetation Trees, under-storey shrubs or non-woody plants present Vegetative disruption minimal					Bank surfaces covered mainly by native vegetation Disruption evident Banks may be covered by exotic forestry					Bank surfaces covered by mixture of grasses/shrubs, blackberry, willow & introduced species Vegetation disruption obvious Bare soil/closely cropped vegetation common					Bank surfaces covered by grasses & shrubs Disruption of stream bank vegetation very high Grass heavily grazed Significant stock damage to bank				
Left bank:	20	19	18	17	16	15	14	13	12	11	10	9	[✓ 8]	7	6	5	4	3	2	1
Right bank:	20	19	18	17	16	15	14	13	12	11	[✓ 10]	9	8	7	6	5	4	3	2	1
Mean: 9																				
3. Bank stability	Banks stable Erosion/bank failure absent/minimal <5% of bank affected					Moderately stable Infrequent, small areas of erosion mostly healed over 5-30% of bank eroded					Moderately unstable 30-60% of bank in reach has areas of erosion High erosion potential during floods					Unstable Many eroded areas 60-100% of bank has erosional scars				
Left bank:	20	19	18	17	16	15	[✓ 14]	13	12	11	10	9	8	7	6	5	4	3	2	1
Right bank:	20	19	18	17	16	15	14	13	12	[✓ 11]	10	9	8	7	6	5	4	3	2	1
Mean: 12.5																				
4. Frequency of riffles	Riffles relatively frequent Distance between riffles divided by stream width=5-7 Variety of habitat is key					Occurrence of riffles infrequent Distance between riffles divided by stream width=7-15					Occasional riffle or run Bottom contours provide some habitat Distance between riffles divided by stream width=15-25					Generally flat water, shallow riffles Poor habitat Distance between riffles divided by stream width=>25				
Score: 14	20	19	18	17	16	15	[✓ 14]	13	12	11	10	9	8	7	6	5	4	3	2	1
5. Channel alteration	Changes to channel/dredging absent/minimal Stream with normal pattern					Some changes to channel/dredging Evidence of past channel/dredging Recent channel/dredging not present					Channel changes/dredging extensive Embankments/shoring structures present on both banks 40-80% of reach channelized & disrupted					Banks shored with gabion/cement >80% of stream reach channelized or disrupted Instream habitat altered/absent				
Score:	[✓ 20]	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1

<table>
<tr><th rowspan="2">Habitat parameter</th><th colspan="5">Category</th><th colspan="5">Habitat parameter</th><th colspan="5">Category</th><th colspan="5">Habitat parameter</th></tr>
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<tr><td>6. Sediment deposition</td><td colspan="5">• Little/no islands or point bars present
• <20% of bottom affected by sediment deposition</td><td colspan="5">• New increase in bar formation, mostly from gravel, sand or fine sediment
• 20-50% of bottom affected
• Slight deposition in pools</td><td colspan="5">• Some deposition of new gravel, sand or fine sediment on old & new bars
• 50-80% of bottom affected
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• >80% of bottom changing frequently
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<tr><td>7. Velocity/depth regimes</td><td colspan="5">• 4 velocity/depth regimes present
• Slow/deep, slow/shallow, fast/shallow, fast/deep</td><td colspan="5">• 3 0f 4 velocity/depth regimes present
• If fast/shallow is missing then score lower</td><td colspan="5">• 2 of 4 velocity/depth regimes present
• If fast/shallow or slow/shallow are missing, score low</td><td colspan="5">• Dominated by 1 velocity/depth regime
• Usually deep/slow</td></tr>
<tr><td>Score: 18</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>8. Abundance & diversity of habitat</td><td colspan="5">• >50% substrate favourable for invertebrate colonisation & wide variety of woody debris, riffles, root mats
• Snags/ submerged logs/undercut banks/cobbles provides abundant fish cover
• Must not be new or transient</td><td colspan="5">• 30-50% substrate favourable for invertebrate colonisation
• Snags/ submerged logs/undercut banks/cobbles
• Fish cover common
• Moderate variety of habitat types. Can consist of some new material</td><td colspan="5">• 10-30% substrate favourable for invertebrate colonisation
• Fish cover patchy
• 60-90% substrate easily moved by foot
• Woody debris rare or may be smothered by sediment</td><td colspan="5">• <10% substrate favourable for invertebrate colonisation
• Fish cover rare or absent
• Substrate unstable or lacking
• Stable habitats lacking or limited to macrophytes</td></tr>
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<tr><td>9. Periphyton</td><td colspan="5">• Periphyton not evident on hand held stones
• Stable substrate
• Surfaces rough to touch</td><td colspan="5">• Periphyton not visible on stones
• Stable substrate
• Periphyton obvious to touch</td><td colspan="5">• Periphyton visible
• <20% cover of available substrates</td><td colspan="5">• Periphyton obvious & prolific
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<tr><td colspan="21">TOTAL SCORE: 136.5</td></tr>
</table>

Field Assessment Cover Form
Wadeable Hard-Bottomed and Soft-Bottomed Streams

Stream name: Omahu Stream (u/s)		Assessor: Paul Franklin	
Site number: 6	Sample number: 6	Date: 12/03/09	Time: 15:20
GPS coordinates	Downstream:	E2746688	N6435516
	Upstream:	E2746806	N6435488

Channel & riparian features

Canopy cover:

Open	**Partly shaded**	Very shaded

Fencing:	Dominant riparian vegetation:	
None/ineffective	Crops	Retired vegetation
One side/partial	Pasture	Native shrub
Complete	**Exotic trees**	Native trees

Instream hydraulic conditions

Estimated or measured reach average:

Stream width (active channel):

Stream width (water):

Stream depth:

Surface velocity:

Water quality

Temperature:	18.6	°C	Conductivity:		µS cm^{-1}
Dissolved oxygen:		%	9.0		mg l^{-1}
Turbidity:	**Clear**	Slightly turbid	Highly turbid	Stained	Other

Stream-bottom substrata

Compaction (inorganic substrata):

Assorted sizes tightly packed &/or overlapping

Moderately packed with some overlapping

Mostly a loose assortment with little overlap

No packing/loose assortment easily moved

Embeddedness:

(% gravel-boulder particles covered by fine sediment)

<5%	5-25%	26-50%	51-75%	>75%

% surficial inorganic substratum size composition:

Substratum	Dimension	Percentage
Bedrock	-	
Boulder	>256mm	
Cobble	>64-256mm	95
Gravel	>2-64mm	
Sand	>0.06-2mm	5
Silt	0.004-0.06mm	
Clay	<0.004mm	

Organic material (% cover)

Large wood (>10cm diameter)

<5%	5-25%	26-50%	51-75%	>75%

Coarse detritus (small wood, sticks, leaves etc. >1mm)

<5%	5-25%	26-50%	51-75%	>75%

Fine (<1mm) organic deposits

<5%	5-25%	26-50%	51-75%	>75%

Instream plant cover (% streambed area)

Filamentous algae & mats:

<5%	5-25%	26-50%	51-75%	>75%

Macrophytes:

<5%	5-25%	26-50%	51-75%	>75%

Mosses/liverworts:

<5%	5-25%	26-50%	51-75%	>75%

Habitat types sampled

(% of effort)

Stones:	100%		
Wood:	%	Riffles:	100 %
Macrophyte:	%	Runs:	%
Edges:	%		

Number of invertebrates returned:

Koura:	Shrimps:
Crabs:	Mussels:
Other:	
Mussel type:	
Hyridella	*Cucumerunio*

Comments:

Wadeable Hard-Bottomed Streams

Qualitative Habitat Assessment Field Data Sheet

Stream name: Omahu Stream (u/s)

Site number: 6

Sample number: 6

Assessor: Paul Franklin

Date: 12/03/09

Habitat parameter	Category																			
	Optimal					Suboptimal					Marginal					Poor				
1. Riparian vegetative zone width	• Bankside vegetation buffer >10m • Continuous & dense					• Bankside vegetation buffer is <10m • Mostly continuous					• Pathways present and/or stock • Mostly healed over					• Breaks frequent • Human activity obvious				
Left bank:	20	19	18	17	16	15	14	13	12	11	10	9	[✓ 8]	7	6	5	4	3	2	1
Right bank:	20	19	18	17	16	15	14	13	12	11	10	9	[✓ 8]	7	6	5	4	3	2	1
Mean: 8																				
2. Vegetative protection	• Bank surfaces & immediate riparian zones covered by native vegetation • Trees, under-storey shrubs or non-woody plants present • Vegetative disruption minimal					• Bank surfaces covered mainly by native vegetation • Disruption evident • Banks may be covered by exotic forestry					• Bank surfaces covered by mixture of grasses/shrubs, blackberry, willow & introduced species • Vegetation disruption obvious • Bare soil/closely cropped vegetation common					• Bank surfaces covered by grasses & shrubs • Disruption of stream bank vegetation very high • Grass heavily grazed • Significant stock damage to bank				
Left bank:	20	19	18	17	16	15	14	13	12	11	10	9	8	7	[✓ 6]	5	4	3	2	1
Right bank:	20	19	18	17	16	15	14	13	12	11	10	9	[✓ 8]	7	6	5	4	3	2	1
Mean: 7																				
3. Bank stability	• Banks stable • Erosion/bank failure absent/minimal • <5% of bank affected					• Moderately stable • Infrequent, small areas of erosion mostly healed over • 5-30% of bank eroded					• Moderately unstable • 30-60% of bank in reach has areas of erosion • High erosion potential during floods					• Unstable • Many eroded areas • 60-100% of bank has erosional scars				
Left bank:	20	19	18	17	16	15	[✓ 14]	13	12	11	10	9	8	7	6	5	4	3	2	1
Right bank:	20	19	18	17	16	15	[✓ 14]	13	12	11	10	9	8	7	6	5	4	3	2	1
Mean: 14																				
4. Frequency of riffles	• Riffles relatively frequent • Distance between riffles divided by stream width=5-7 • Variety of habitat is key					• Occurrence of riffles infrequent • Distance between riffles divided by stream width=7-15					• Occasional riffle or run • Bottom contours provide some habitat • Distance between riffles divided by stream width=15-25					• Generally flat water, shallow riffles • Poor habitat • Distance between riffles divided by stream width=>25				
Score: 15	20	19	18	17	16	[✓ 15]	14	13	12	11	10	9	8	7	6	5	4	3	2	1
5. Channel alteration	• Changes to channel/dredging absent/minimal • Stream with normal pattern					• Some changes to channel/dredging • Evidence of past channel/dredging • Recent channel/dredging not present					• Channel changes/dredging extensive • Embankments/shoring structures present on both banks • 40-80% of reach channelized & disrupted					• Banks shored with gabion/cement • >80% of stream reach channelized or disrupted • Instream habitat altered/absent				
Score: 15	20	19	18	17	16	[✓ 15]	14	13	12	11	10	9	8	7	6	5	4	3	2	1

Habitat parameter	Category	Habitat parameter	Category	Habitat parameter
	Optimal		Optimal	
6. Sediment deposition	- Little/no islands or point bars present - <20% of bottom affected by sediment deposition	- New increase in bar formation, mostly from gravel, sand or fine sediment - 20-50% of bottom affected - Slight deposition in pools	- Some deposition of new gravel, sand or fine sediment on old & new bars - 50-80% of bottom affected - Sediment deposits at obstructions, constrictions & bends	- Heavy deposits of fine material - Increased bar development - >80% of bottom changing frequently - Pools almost absent due to sediment deposition
Score: 16	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
7. Velocity/depth regimes	- 4 velocity/depth regimes present - Slow/deep, slow/shallow, fast/shallow, fast/deep	- 3 0f 4 velocity/depth regimes present - If fast/shallow is missing then score lower	- 2 of 4 velocity/depth regimes present - If fast/shallow or slow/shallow are missing, score low	- Dominated by 1 velocity/depth regime - Usually deep/slow
Score: 18	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
8. Abundance & diversity of habitat	- >50% substrate favourable for invertebrate colonisation & wide variety of woody debris, riffles, root mats - Snags/ submerged logs/undercut banks/cobbles provides abundant fish cover - Must not be new or transient	- 30-50% substrate favourable for invertebrate colonisation - Snags/ submerged logs/undercut banks/cobbles - Fish cover common - Moderate variety of habitat types. Can consist of some new material	- 10-30% substrate favourable for invertebrate colonisation - Fish cover patchy - 60-90% substrate easily moved by foot - Woody debris rare or may be smothered by sediment	- <10% substrate favourable for invertebrate colonisation - Fish cover rare or absent - Substrate unstable or lacking - Stable habitats lacking or limited to macrophytes
Score: 18	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
9. Periphyton	- Periphyton not evident on hand held stones - Stable substrate - Surfaces rough to touch	- Periphyton not visible on stones - Stable substrate - Periphyton obvious to touch	- Periphyton visible - <20% cover of available substrates	- Periphyton obvious & prolific - >20% cover of available substrates
Score: 16	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1
TOTAL SCORE: 127				

Field Assessment Cover Form
Wadeable Hard-Bottomed and Soft-Bottomed Streams

Stream name: Unnamed trib. of Homunga Stream (d/s)		Assessor: Paul Franklin	
Site number: 7	Sample number: 7	Date: 13/03/09	Time: 14:30
GPS coordinates	Downstream:	E2765475	N6420947
	Upstream:	E2765584	N6421032

Channel & riparian features

Canopy cover:

Open	Partly shaded	Very shaded

Fencing:	Dominant riparian vegetation:	
None/ineffective	Crops	Retired vegetation
One side/partial	**Pasture**	Native shrub
Complete	Exotic trees	Native trees

Instream hydraulic conditions

Estimated or measured reach average:

Stream width (active channel): 5 m

Stream width (water): 2.3 m

Stream depth: 0.6 m

Surface velocity: 0.3 m s^{-1}

Water quality

Temperature:	16.1	°C	Conductivity:	µS cm^{-1}
Dissolved oxygen:	87	%	8.6	mg l^{-1}

Turbidity:	**Clear**	Slightly turbid	Highly turbid	Stained	Other

Stream-bottom substrata

Compaction (inorganic substrata):

Assorted sizes tightly packed &/or overlapping

Moderately packed with some overlapping

Mostly a loose assortment with little overlap

No packing/loose assortment easily moved

Embeddedness:

(% gravel-boulder particles covered by fine sediment)

<5%	**5-25%**	26-50%	51-75%	>75%

% surficial inorganic substratum size composition:

Substratum	Dimension	Percentage
Bedrock	-	
Boulder	>256mm	
Cobble	>64-256mm	40
Gravel	>2-64mm	10
Sand	>0.06-2mm	50
Silt	0.004-0.06mm	
Clay	<0.004mm	

Organic material (% cover)

Large wood (>10cm diameter)

<5%	5-25%	26-50%	51-75%	>75%

Coarse detritus (small wood, sticks, leaves etc. >1mm)

<5%	**5-25%**	26-50%	51-75%	>75%

Fine (<1mm) organic deposits

<5%	5-25%	26-50%	51-75%	>75%

Habitat types sampled

(% of effort)

Stones:	100%	Riffles:	100 %
Wood:	%	Runs:	%
Macrophyte:	%		
Edges:	%		

Instream plant cover (% streambed area)

Filamentous algae & mats:

<5%	5-25%	26-50%	51-75%	>75%

Macrophytes:

<5%	5-25%	26-50%	51-75%	>75%

Mosses/liverworts:

<5%	5-25%	26-50%	51-75%	>75%

Number of invertebrates returned:

Koura:	Shrimps:
Crabs:	Mussels:
Other:	
Mussel type:	
Hyridella	*Cucumerunio*

Comments:

Wadeable Hard-Bottomed Streams

Qualitative Habitat Assessment Field Data Sheet

Stream name: Unnamed trib. Homunga Stream (d/s)
Site number: 7
Sample number: 7
Assessor: Paul Franklin
Date: 13/03/09

Habitat parameter	Category Optimal	 Suboptimal	 Marginal	 Poor
1. Riparian vegetative zone width	• Bankside vegetation buffer >10m • Continuous & dense	• Bankside vegetation buffer is <10m • Mostly continuous	• Pathways present and/or stock • Mostly healed over	• Breaks frequent • Human activity obvious
Left bank:	20 19 18 17 16	15 14 13 12 [✓ 11]	10 9 8 7 6	5 4 3 2 1
Right bank:	20 19 18 17 16	15 14 13 12 [✓ 11]	10 9 8 7 6	5 4 3 2 1
Mean: 11				
2. Vegetative protection	• Bank surfaces & immediate riparian zones covered by native vegetation • Trees, under-storey shrubs or non-woody plants present • Vegetative disruption minimal	• Bank surfaces covered mainly by native vegetation • Disruption evident • Banks may be covered by exotic forestry	• Bank surfaces covered by mixture of grasses/shrubs, blackberry, willow & introduced species • Vegetation disruption obvious • Bare soil/closely cropped vegetation common	• Bank surfaces covered by grasses & shrubs • Disruption of stream bank vegetation very high • Grass heavily grazed • Significant stock damage to bank
Left bank:	20 19 18 17 16	15 14 13 12 11	10 9 8 7 [✓ 6]	5 4 3 2 1
Right bank:	20 19 18 17 16	15 14 13 12 11	10 9 8 7 [✓ 6]	5 4 3 2 1
Mean: 6				
3. Bank stability	• Banks stable • Erosion/bank failure absent/minimal • <5% of bank affected	• Moderately stable • Infrequent, small areas of erosion mostly healed over • 5-30% of bank eroded	• Moderately unstable • 30-60% of bank in reach has areas of erosion • High erosion potential during floods	• Unstable • Many eroded areas • 60-100% of bank has erosional scars
Left bank:	20 19 18 17 16	15 14 13 [✓ 12] 11	10 9 8 7 6	5 4 3 2 1
Right bank:	20 19 18 17 16	15 [✓ 14] 13 12 11	10 9 8 7 6	5 4 3 2 1
Mean: 13				
4. Frequency of riffles	• Riffles relatively frequent • Distance between riffles divided by stream width=5-7 • Variety of habitat is key	• Occurrence of riffles infrequent • Distance between riffles divided by stream width=7-15	• Occasional riffle or run • Bottom contours provide some habitat • Distance between riffles divided by stream width=15-25	• Generally flat water, shallow riffles • Poor habitat • Distance between riffles divided by stream width=>25
Score: 12	20 19 18 17 16	15 14 13 [✓ 12] 11	10 9 8 7 6	5 4 3 2 1
5. Channel alteration	• Changes to channel/dredging absent/minimal • Stream with normal pattern	• Some changes to channel/dredging • Evidence of past channel/dredging • Recent channel/dredging not present	• Channel changes/dredging extensive • Embankments/shoring structures present on both banks • 40-80% of reach channelized & disrupted	• Banks shored with gabion/cement • >80% of stream reach channelized or disrupted • Instream habitat altered/absent
Score: 16	20 19 18 17 [✓ 16]	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1

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• Fish cover patchy
• 60-90% substrate easily moved by foot
• Woody debris rare or may be smothered by sediment</td><td colspan="5">• <10% substrate favourable for invertebrate colonisation
• Fish cover rare or absent
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• Stable substrate
• Periphyton obvious to touch</td><td colspan="5">• Periphyton visible
• <20% cover of available substrates</td><td colspan="5">• Periphyton obvious & prolific
• >20% cover of available substrates</td></tr>
<tr><td>Score: 15</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td colspan="21">TOTAL SCORE: 118</td></tr>
</table>

Field Assessment Cover Form

Wadeable Hard-Bottomed and Soft-Bottomed Streams

Stream name: Unnamed trib. of Homunga Stream (u/s)		Assessor: Paul Franklin	
Site number: 8	Sample number: 8	Date: 13/03/09	Time: 11:00
GPS coordinates	Downstream:	E2765847	N6420687
	Upstream:	E	N

Channel & riparian features

Canopy cover:

Open	Partly shaded	Very shaded

Fencing:	Dominant riparian vegetation:	
None/ineffective	Crops	**Retired vegetation**
One side/partial	Pasture	Native shrub
Complete	Exotic trees	Native trees

Instream hydraulic conditions

Estimated or measured reach average:

Stream width (active channel): 5 m

Stream width (water): 3 m

Stream depth: 0.5 m

Surface velocity: 0.3 m s^{-1}

Water quality

Temperature:		°C	Conductivity:		µS cm^{-1}
Dissolved oxygen:		%			mg l^{-1}
Turbidity:	**Clear**	Slightly turbid	Highly turbid	Stained	Other

Stream-bottom substrata

Compaction (inorganic substrata):

Assorted sizes tightly packed &/or overlapping

Moderately packed with some overlapping

Mostly a loose assortment with little overlap

No packing/loose assortment easily moved

Embeddedness:

(% gravel-boulder particles covered by fine sediment)

<5%	**5-25%**	26-50%	51-75%	>75%

% surficial inorganic substratum size composition:

Substratum	Dimension	Percentage
Bedrock	-	5
Boulder	>256mm	10
Cobble	>64-256mm	10
Gravel	>2-64mm	10
Sand	>0.06-2mm	65
Silt	0.004-0.06mm	
Clay	<0.004mm	

Organic material (% cover)

Large wood (>10cm diameter)

<5%	5-25%	26-50%	51-75%	>75%

Coarse detritus (small wood, sticks, leaves etc. >1mm)

<5%	5-25%	26-50%	51-75%	>75%

Fine (<1mm) organic deposits

<5%	5-25%	26-50%	51-75%	>75%

Instream plant cover (% streambed area)

Filamentous algae & mats:

<5%	5-25%	26-50%	51-75%	>75%

Macrophytes:

<5%	5-25%	26-50%	51-75%	>75%

Mosses/liverworts:

<5%	5-25%	26-50%	51-75%	>75%

Habitat types sampled

(% of effort)

Stones:	100%	Riffles:	100 %
Wood:	%	Runs:	%
Macrophyte:	%		
Edges:	%		

Number of invertebrates returned:

Koura:	Shrimps:
Crabs:	Mussels:
Other:	
Mussel type:	
Hyridella	*Cucumerunio*

Comments:

Wadeable Hard-Bottomed Streams

Qualitative Habitat Assessment Field Data Sheet

Stream name: Unnamed trib. Homunga Stream (u/s)
Site number: 8
Sample number: 8
Assessor: Paul Franklin
Date: 13/03/09

Habitat parameter	Category																			
	Optimal					Suboptimal					Marginal					Poor				
1. Riparian vegetative zone width	• Bankside vegetation buffer >10m • Continuous & dense					• Bankside vegetation buffer is <10m • Mostly continuous					• Pathways present and/or stock • Mostly healed over					• Breaks frequent • Human activity obvious				
Left bank:	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Right bank:	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Mean: 9																				
2. Vegetative protection	• Bank surfaces & immediate riparian zones covered by native vegetation • Trees, under-storey shrubs or non-woody plants present • Vegetative disruption minimal					• Bank surfaces covered mainly by native vegetation • Disruption evident • Banks may be covered by exotic forestry					• Bank surfaces covered by mixture of grasses/shrubs, blackberry, willow & introduced species • Vegetation disruption obvious • Bare soil/closely cropped vegetation common					• Bank surfaces covered by grasses & shrubs • Disruption of stream bank vegetation very high • Grass heavily grazed • Significant stock damage to bank				
Left bank:	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Right bank:	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Mean: 10																				
3. Bank stability	• Banks stable • Erosion/bank failure absent/minimal • <5% of bank affected					• Moderately stable • Infrequent, small areas of erosion mostly healed over • 5-30% of bank eroded					• Moderately unstable • 30-60% of bank in reach has areas of erosion • High erosion potential during floods					• Unstable • Many eroded areas • 60-100% of bank has erosional scars				
Left bank:	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Right bank:	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Mean: 15																				
4. Frequency of riffles	• Riffles relatively frequent • Distance between riffles divided by stream width=5-7 • Variety of habitat is key					• Occurrence of riffles infrequent • Distance between riffles divided by stream width=7-15					• Occasional riffle or run • Bottom contours provide some habitat • Distance between riffles divided by stream width=15-25					• Generally flat water, shallow riffles • Poor habitat • Distance between riffles divided by stream width=>25				
Score: 12	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
5. Channel alteration	• Changes to channel/dredging absent/minimal • Stream with normal pattern					• Some changes to channel/dredging • Evidence of past channel/dredging • Recent channel/dredging not present					• Channel changes/dredging extensive • Embankments/shoring structures present on both banks • 40-80% of reach channelized & disrupted					• Banks shored with gabion/cement • >80% of stream reach channelized or disrupted • Instream habitat altered/absent				
Score:17	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1

<table>
<tr><th rowspan="2">Habitat parameter</th><th colspan="5">Category</th><th colspan="5" rowspan="2">Habitat parameter</th><th colspan="5">Category</th><th colspan="5" rowspan="2">Habitat parameter</th></tr>
<tr><th colspan="5">Optimal</th><th colspan="5">Optimal</th></tr>
<tr><td>6. Sediment deposition</td><td colspan="5">• Little/no islands or point bars present
• <20% of bottom affected by sediment deposition</td><td colspan="5">• New increase in bar formation, mostly from gravel, sand or fine sediment
• 20-50% of bottom affected
• Slight deposition in pools</td><td colspan="5">• Some deposition of new gravel, sand or fine sediment on old & new bars
• 50-80% of bottom affected
• Sediment deposits at obstructions, constrictions & bends</td><td colspan="5">• Heavy deposits of fine material
• Increased bar development
• >80% of bottom changing frequently
• Pools almost absent due to sediment deposition</td></tr>
<tr><td>Score: 17</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>7. Velocity/depth regimes</td><td colspan="5">• 4 velocity/depth regimes present
• Slow/deep, slow/shallow, fast/shallow, fast/deep</td><td colspan="5">• 3 0f 4 velocity/depth regimes present
• If fast/shallow is missing then score lower</td><td colspan="5">• 2 of 4 velocity/depth regimes present
• If fast/shallow or slow/shallow are missing, score low</td><td colspan="5">• Dominated by 1 velocity/depth regime
• Usually deep/slow</td></tr>
<tr><td>Score: 13</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>8. Abundance & diversity of habitat</td><td colspan="5">• >50% substrate favourable for invertebrate colonisation & wide variety of woody debris, riffles, root mats
• Snags/ submerged logs/undercut banks/cobbles provides abundant fish cover
• Must not be new or transient</td><td colspan="5">• 30-50% substrate favourable for invertebrate colonisation
• Snags/ submerged logs/undercut banks/cobbles
• Fish cover common
• Moderate variety of habitat types. Can consist of some new material</td><td colspan="5">• 10-30% substrate favourable for invertebrate colonisation
• Fish cover patchy
• 60-90% substrate easily moved by foot
• Woody debris rare or may be smothered by sediment</td><td colspan="5">• <10% substrate favourable for invertebrate colonisation
• Fish cover rare or absent
• Substrate unstable or lacking
• Stable habitats lacking or limited to macrophytes</td></tr>
<tr><td>Score: 14</td><td>20</td><td>19</td><td>18</td><td>17</td><td>16</td><td>15</td><td>14</td><td>13</td><td>12</td><td>11</td><td>10</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
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<tr><td colspan="21">TOTAL SCORE: 119</td></tr>
</table>

10. Appendix 5 – RVA as a context for minimum flows

The following is provided as an example of how the RVA results can be used as part of the decision making process for determination of flow allocation rules. The authors would like to emphasise that this is provided as a purely hypothetical example to illustrate the complementary way in which different components of the flow assessment process can be combined to inform flow management decision making. In no way should this be considered as a recommendation for or against any particular method or result.

Minimum flow requirements for fish habitat protection in the Waihou were determined by Jowett (2008). In the following two examples, the minimum flow requirements determined for adult trout are compared to the natural range of variability in 7-day low flows calculated using the RVA approach for two sites (Figure 10.1 and Figure 10.2).

The first example was taken from the Karangahake site on the Ohinemuri River (Figure 10.1). The minimum flows proposed as necessary for the preservation of adult trout habitat at this site all fall above the natural range of 7-day low flows. This could be interpreted to mean that adult trout populations are naturally restricted by low flows in this part of the catchment. Consequently, any further reduction in low flows will result in a reduction of suitable habitat and potentially a reduction in trout. If the trout fishery is highly valued then this may be an undesirable outcome and low flows should be protected from exploitation. However, trout are only one component of the fish community and it may be that the natural restriction in their optimum habitat will result in benefits for native fish species by reducing competition. If the success of native fish populations was valued more highly than trout, and optimum flows for native fish were lower than the natural range of low flows, then some exploitation of water may be encouraged to support this value.

The second example is representative of the Waihou River downstream of Gordon (Figure 10.2). It can be seen that in this case the optimum flows for maintaining suitable trout habitat were considerably lower than the natural range of 7-day low flows. If the trout fishery was highly valued, it could be argued that a significant proportion of river flow could be allocated to consumptive uses and this may enhance trout habitat. However, it could also be argued that such use would result in flows significantly outside of the natural range of variability and consequently outside of the range of flows to which the aquatic ecosystem is adapted. Flora and fauna other than trout, along with important physico-chemical processes (e.g., changes in water temperature, dissolved oxygen or sedimentation), may be adversely affected by reductions in flow outside of the natural range of variability, with a subsequent degradation in the river.

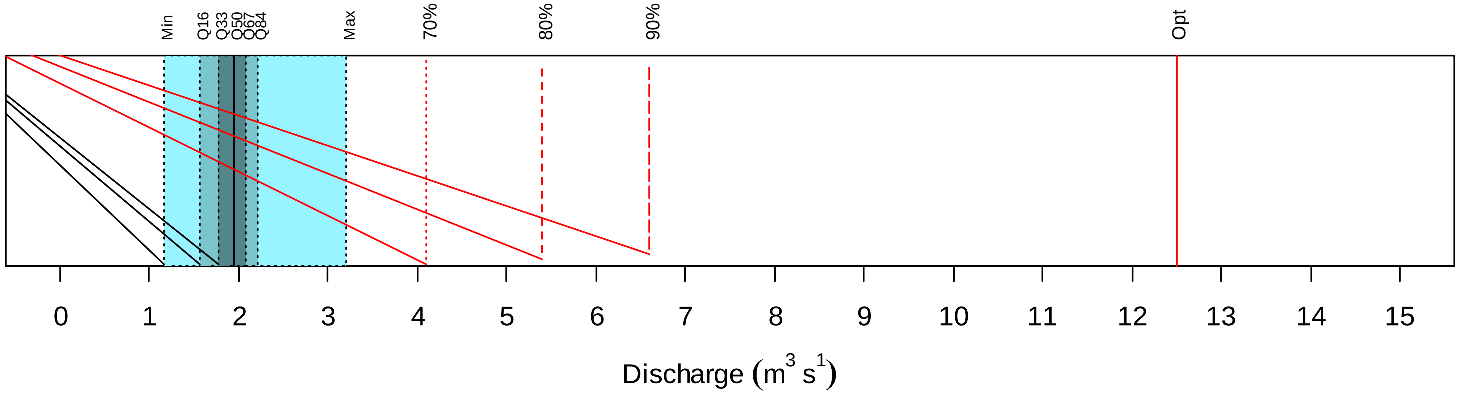

Figure 10.1: Natural range of variability in 7-day flow minimum (RVA) compared to minimum flow requirements for adult trout (RHYHABSIM) for the Ohinemuri River at Karangahake. Red lines represent flows offering differing levels of habitat protection (Opt=Optimum; 70%=70% of optimum). The ranges in 7-day low flows between minimum and maximum, 16th and 84th percentiles and 33rd and 67th percentiles are shown by the blue shaded areas and the median flow (Q50) by the solid black line.

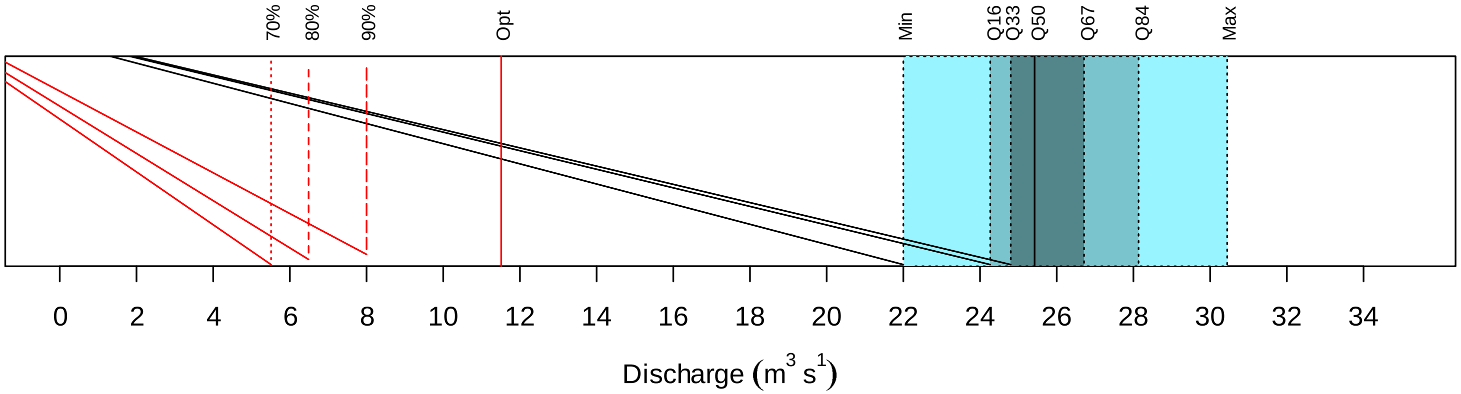

Figure 10.2: Natural range of variability in 7-day flow minimum (RVA) compared to minimum flow requirements for adult trout (RHYHABSIM) for the Waihou River downstream of Gordon. Flow statistics are calculated for the Te Aroha gauging site.