# Proposed
# Hurunui and Waiau River Regional Plan

# And Proposed Plan Change 3 to the Canterbury Natural Resources Regional Plan

## Section 42A Report
September 2012

## Changes to river flows and consequences for periphyton

**Prepared by**

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Environment Canterbury
Regional Council
Kaunihera Taiao ki Waitaha

# 1. Introduction

## 1.1 Author

1. My name is Antonius (Ton) Hugh Snelder. I am a principal scientist in Freshwater Ecology at the National Institute of Water and Atmospheric Research (NIWA). I have 23 years of experience in the field of water resource management including 14 years as a water resources scientist at NIWA. Prior to my current position I worked for regional councils and in consultancies as a water resources engineer. In my position at NIWA I have lead many projects that have assessed the effects of water takes and discharges on river environments. I have written a number of guidelines for the management of water quality and quantity and developed several tools for water management purposes. I have authored or co-authored several scientific publications in the field of river management, including those that address flow regimes of rivers.

2. Although this is a Council Hearing, I have read the Code of Conduct for Expert Witnesses contained in the Environment Court's Consolidated Practice Note dated 1 November 2011. I have complied with that Code when preparing my written statement of evidence and I agree to comply with it when I give any oral evidence.

3. The scope of my evidence relates to the effects of allocation of water to out of channel uses under the Hurunui and Waiau River Regional Plan (HWRRP). In particular, there will be changes to mid-range flows including altering the frequency and duration of high and low flows. My evidence will cover how these alterations are likely to alter periphyton (i.e. algae growing on the river bed). I confirm that the issues addressed in this statement of evidence are generally within my area of expertise. Hydraulic conditions (i.e. water depth and velocity) are not within my area of expertise, and in those respects, I am relying upon evidence provided by Maurice Duncan.

4. I have not omitted to consider material facts known to me that might alter or detract from the opinions expressed.

5. The key study on which I have used in support of my opinions are described in a report to CRC (Snelder et al. 2011).

6. The data on which I have relied are measurements of discharge, water quality and periphyton cover in the Hurunui and Waiau rivers. The flow records for the Hurunui and Waiau rivers were used to simulate several flow allocation scenarios by Dr Jeff Smith at CRC. I have used these simulated flows as a key component of my analysis. The water quality and periphyton cover data were collected by NIWA as part of the National River Water Quality Network (NRWQN) and have been compiled by sampling water quality and periphyton at monthly intervals at 77 river sites across New Zealand since 1989. I also acknowledge the use of a short time series of periphyton cover (visual estimates) in the Waiau River comprising 86 observations since 2004. These data were collected by CRC

## 1.2 Content of the officer's report

7. This report is prepared under the provisions of section 42A of the Resource Management Act 1991 (RMA).

## 1.3 Explanation of terms and coding used in the report

| | |
|---|---|
| CRC | Canterbury Regional Council or Environment Canterbury (ECan) |
| CWMS | Canterbury Water Management Strategy |
| DIN | Dissolved Inorganic Nitrogen |
| DRP | Dissolved Reactive Phosphorous |
| HWRRP | Proposed Hurunui and Waiau River Regional Plan |
| L/s | Litres per second |
| Log Scale | A logarithmic scale is a scale of measurement using the logarithm of a physical quantity (in this case river flow) instead of the quantity itself. Take a chart whose vertical y-axis has equally spaced increments that are labeled 1, 10, 100, 1000, instead of 1, 2, 3, 4. Each unit increase on the logarithmic scale thus represents an exponential increase in the underlying quantity for the given base (10, in this case). Data presentation on a logarithmic scale is helpful when the data covers a large range of values, for example a river which might have a mean annual low flow of around 70 $m^3$/s, a mean flow of around 200 $m^3$/s, and a peak flood flow of around 4000 $m^3$/s. The use of the logarithms of the values rather than the actual values therefore reduces a wide range to a more manageable size, and provides for better interpretation around key values (flows) of interest. |
| $m^3$/s | Cumec (A measure of river flow. One (1) cumec is the equivalent to one (1) cubic metre per second or alternatively 1,000 L/s) |
| MALF or MALF7d | Mean Annual Seven Day Low Flow |
| NRRP | Natural Resources Regional Plan |

# 2 SCOPE OF EVIDENCE

8. I have been asked by CRC to prepare evidence in relation to the effects of the water allocation that could occur in the Hurunui and Waiau rivers under the HWRRP. The HWRRP has objectives and policies in relation to the allocation of water for out-of-channel use. I have been asked to provide evidence concerning the effects of plan implementation on environmental values, including the risks, assumptions and the uncertainties associated with the effects assessment.

9. Specifically, my evidence includes;

   i. a general description of the flow regimes of the Hurunui and Waiau rivers;

   ii. a general description of the water allocation scenarios for the Hurunui and Waiau rivers that could occur under the HWRRP;

   iii. a description of the changes to the flow regimes of the Hurunui and Waiau rivers under the water allocation scenarios;

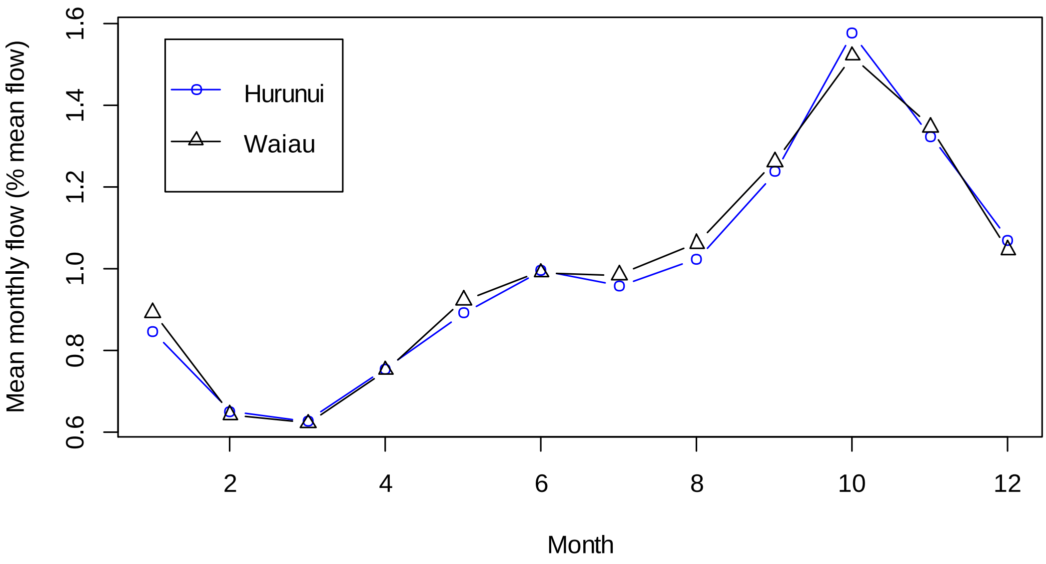
   iv. and a description of the impact of these flow regime changes on periphyton in the rivers.

# 3 FLOW REGIMES OF THE HURUNUI AND WAIAU RIVERS

10. Flows have been recorded for the Hurunui River at Mandamus and the Waiau River at Marble Point from 1960 and 1966 respectively, to the present time. The mean daily flow records were naturalised (i.e. historical abstractions were added to the recorded flows) by CRC staff and these records were then used as the basis for the analyses that are discussed below. Based on the mean daily flow time series, the natural median and mean flows of the Hurunui River are 39 and 52 $m^3/s$ respectively. The natural median and mean flows of the Waiau River are 73 and 97 $m^3/s$ respectively. The natural mean 7-day annual low flow (MALF) for the Hurunui and Waiau rivers are 16 and 32 $m^3/s$ respectively and the mean annual flood flow for the rivers are approximately 363 and 672 $m^3/s$ respectively.

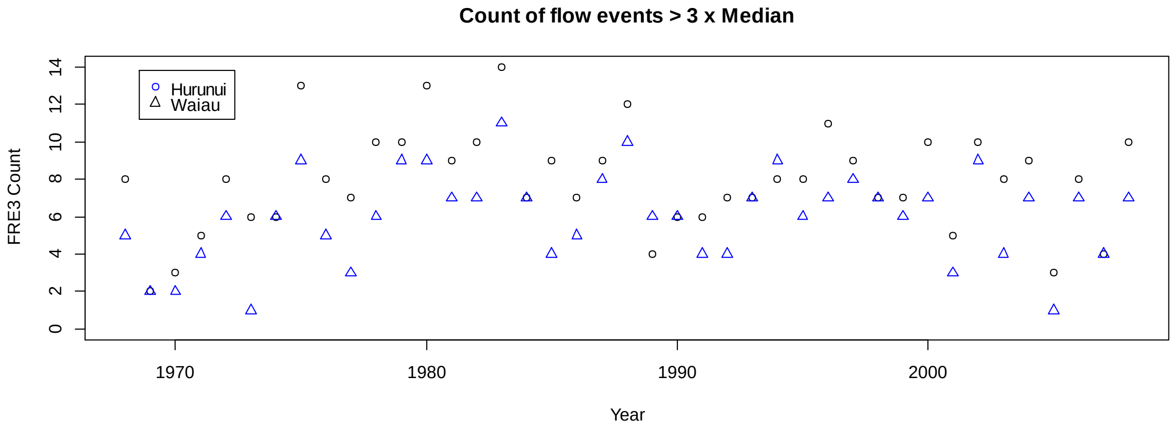
11. The hydrology of the lower Hurunui and Waiau Rivers are characterised by within-year flow variability (frequent high flows and periods of low flow). Annual hydrographs for both rivers are characterised by flows that are more stable and higher in winter months (July to September inclusive), which is typical of Canterbury rivers that have mainly mountainous catchments (Figure 1). These stable flows occur because much of the precipitation in the headwaters falls as snow in this period and does not melt until spring. Annual hydrographs are also characterised by higher flows during spring that are associated with snow melt (October to November inclusive) (Figure 1). The hydrographs also show that late summer and autumn can be associated with low flow periods.

**Figure 1. The natural annual flow regimes of Hurunui and Waiau Rivers. The plotted values are the mean flow in each month (January = 1) calculated from the entire time series for both rivers, divided by to the long term mean daily flow.**



12. As well as within year variability there is also considerable between-year flow variability associated with wet years and drought years. For example, the 7-day annual low flows in the Waiau River have ranged between 19.7 and 45 $m^3$/s. There is also between year variability for high flows. For example, the frequency of floods (as defined by events with flows greater than three times the median) in the Hurunui range between once and seventeen times with a mean of 5.8 and in the Waiau range between 2 and 14 times per year with a mean of 9.9 times per year (Figure 2).

**Figure 2. Variation in the number of flow events with discharge exceeding 3 times the natural median flow for each year of record for the Hurunui at Mandamus and Waiau river at Marble Point.**



# 4 WATER ALLOCATION SCENARIOS FOR THE HURUNUI AND WAIAU RIVERS

13. CRC staff defined water allocation scenarios for both the Hurunui and Waiau Rivers that encompassed the range of water abstraction that may be allowable under the HWRRP. The water allocation scenarios comprise different minimum flow and total allocations. The minimum flow is the river discharge at which abstractions must be restricted to ensure flows are not lowered by abstraction below the minimum. The purpose of the minimum flow is to maintain instream values. The total allocation is the total rate that water can be abstracted from the river. These minimum flows and allocations are divided into management blocks including A, B and C-block allocations. These allocation blocks are associated with differing minimum flows and, therefore, levels of reliability for abstractors with the A block being the most reliable and the C-block being the least.

14. I have used river flow data for the Hurunui and Waiau rivers that were supplied by Dr Smith. For both rivers Dr Smith provided flow data pertaining to the natural flow (i.e. the river flow for the entire period of record that would have occurred had there been no abstraction). For the Hurunui River Dr Smith also provided flow data pertaining to the status quo (i.e. the river flow for the entire period of record that would have occurred if the existing abstraction regime had been in place over that period). Dr Smith also provided flow data for four water allocation scenarios for the Hurunui River and five for the Waiau River. The scenarios data pertain to the entire period of these records and assume differing levels of water abstraction that may be allowable for both rivers under the HWRRP (see Table 1 and 2). These are the same flow allocation scenarios used by other witnesses for CRC and are described in detail in the evidence of Dr Smith. Dr Smith has generated additional scenarios to answer questions related to specific submissions. The scenarios presented in my evidence do not represent a specific development proposal. Rather, they encompass the range of potential effects possible under the HWRRP from the minimum (natural or status quo) to the maximum effect corresponding to the maximum allocation possible under the HWRRP.

15. Four water allocation scenarios for the Hurunui River comprise different total allocation and sizes of A, B and C-block allocations (Table 1). The Hurunui A-block minimum flows are 15 m$^{3}$`s$^{-1}$ September to April and 12 m$^{3}$/s for May to August. B and C-block minimum flows are 27 m3/s and 37 m$^{3}$/s respectively from September to April and 19 m$^{3}$/s and 29 m3/s for the rest of the year. The A Block allocation is 7 m$^{3}$/s and the B Block allocation is 10 m$^{3}$/s. Two options were included to evaluate the C Block allocation. First a seasonal C block comprising no take from December to February (Summer), a take of 16.5 m$^{3}$/s for March to May and September to November (Autumn and Spring) and a take of 33 m$^{3}$/s for June to August (Winter).

**Table 1. Water allocation assessed for the Hurunui River.**

| Scenario name | A-block (m$^{3}$/s) | B-block (m$^{3}$/s) | C-Block (m$^{3}$/s) |
|---|---|---|---|
| Scenario 1 | 7 | | |
| Scenario 2 | 7 | 10 | |
| Scenario 3 | 7 | 10 | 16.5 (Autumn and Spring) 33 (Winter) |
| Scenario 4 | 7 | 10 | 33 (All year) |

16. Five water allocation scenarios for the Waiau River comprise different total allocation and sizes of A and B-block allocations (Table 2). A minimum flow of 20 m$^{3}$/s applies to all scenarios. Scenarios 1, 2 and 3 have single A-blocks of 18, 35 and 71 m$^{3}$/s. Water allocation scenarios 4 and 5 separate the takes into A and B-blocks with gaps between the blocks. Scenario 4 has an A-block of 18 m$^{3}$/s, a gap of 2 m$^{3}$/s and a B-block of 11 m$^{3}$/s. Scenario 5 has an A-block of 18 m$^{3}$/s, a gap of 2 m$^{3}$/s and a B-block of 53 m$^{3}$/s.

17. In my evidence I have compared the effects of the allocation scenarios with each other and the natural flow (as provided by ECan).

**Table 2 Water allocation scenarios assessed in for the Waiau River.**

| Scenario name | A-block (m$^{3}$/s) | Gap (m$^{3}$/s) | B-block (m$^{3}$/s) |
|---|---|---|---|
| Scenario 1 | 18 | | |
| Scenario 2 | 35 | | |
| Scenario 3 | 71 | | |
| Scenario 4 | 18 | 2 | 11 |
| Scenario 5 | 18 | 2 | 53 |

# 5 CHANGES TO THE FLOW REGIMES OF THE HURUNUI AND WAIAU RIVERS UNDER THE WATER ALLOCATION SCENARIOS

18. The importance of maintaining some level of flow in rivers means that minimum flows are the primary limits that need to be defined to manage out of

channel water use. However, the total allocation has a significant influence on the variability of the residual flows in the river (i.e. the modified flow regime). Increased total allocation increases the duration that river flows are held constant at the minimum flow (termed “flat-lining”). These periods of steady and low flow can lead to build up of fine sediment and periphyton (algae that grows on the river bed). In addition when the total allocation is large, there can be changes to the “mid-range” flows, which I define as flows between the mean annual low flow and the mean annual flood flow. Mid-range flows drive important physical and ecological processes including: mobilising and transporting bed material and thereby maintaining channel morphology, reducing and removing fine sediment and periphyton and triggering flow dependent life-stage processes such as fish migration.

19. The maximum total allocations under the HWRRP for the Hurunui and Waiau rivers are 50 $m^3$/s and 71 $m^3$/s respectively. These total allocations are large proportions of the median flows in the Hurunui and Waiau rivers, which are 39.4 $m^3$/s and 73 $m^3$/s respectively. Under the plan, therefore, significant changes to mid-range flows could occur in both rivers.

20. The consequences of the water allocation scenarios for residual flow must be determined by making a hydrological simulation analysis. These analyses simulate the allowable abstraction that can occur for each day of flow record based on the minimum flow and total allocation that are allowed under a specific water allocation scenario. The residual flow for each day is determined by subtracting the allowable abstraction from the natural flow. CRC staff made these hydrological simulation analyses for the both rivers for the scenarios described above. I have analysed these residual flows to describe the modified flow regime under the water allocation scenarios.

21. The natural and residual flows in the Hurunui and Waiau rivers under the water allocation scenarios are illustrated by the hydrographs shown in Figure 3 and Figure 4. The figures show that, for each scenario, the residual flow (red lines) are always less than the natural flow (black line) and that the reduction in flow increases with the increasing total allocation that is allowed by the scenarios. Flat lines indicate time periods that the river will be flat-lined. The duration of flat-lining increases with the increasing total allocation that is allowed under the scenarios.

22. The change to the entire flow regime can be summarised using flow duration curves. The flow duration curve (FDC) represents the relationship between magnitude and frequency of flow by defining the proportion of time for which any discharge is equalled or exceeded. Figure 5 shows FDCs for the Hurunui River for the natural flow and the five flow allocation scenarios. The figures show that, for a given exceedance percentile, the residual flow (red lines) would always be less than the natural flow (black line) and that the reduction in flow increases with the total allocation allowed under the scenarios. The duration of flat-lining increases with the total allocation allowed under the scenarios. For example, under the Scenario 4, flow would be held at the A-block minimum of 15 $m^3$/s for approximately 25% of the time, in comparison with approximately 10% of the time under Scenario 2. Equivalent FDCs for the Waiau River are provided in the report Waiau River Mid-Range Flows Evaluation (Snelder et al., 2011).

23. Flow duration curves for the Hurunui River for each of the five allocation scenarios by season are shown in Figure 6. The seasonal flow duration

curves show that natural flows are more stable in winter and are most variable, and fall to the lowest levels, in summer. Under each allocation scenario, flow would be held at the minimum flow (i.e. flat-lined) for longer in summer than any other season. Differences between scenarios within seasons can also be seen. For example, the duration of flat-lining during summer would be less for the Scenario 3 allocation scenario compared to the Scenario 4.

**Figure 3.** **Annual hydrograph for the Hurunui River at Mandamus for 1987, which was chosen to represent a typical year. The plots show the natural flow hydrograph (black) and the simulated hydrographs (red) for the status quo and each of the four allocation scenarios. Note that the vertical axis (discharge) is a log scale.**

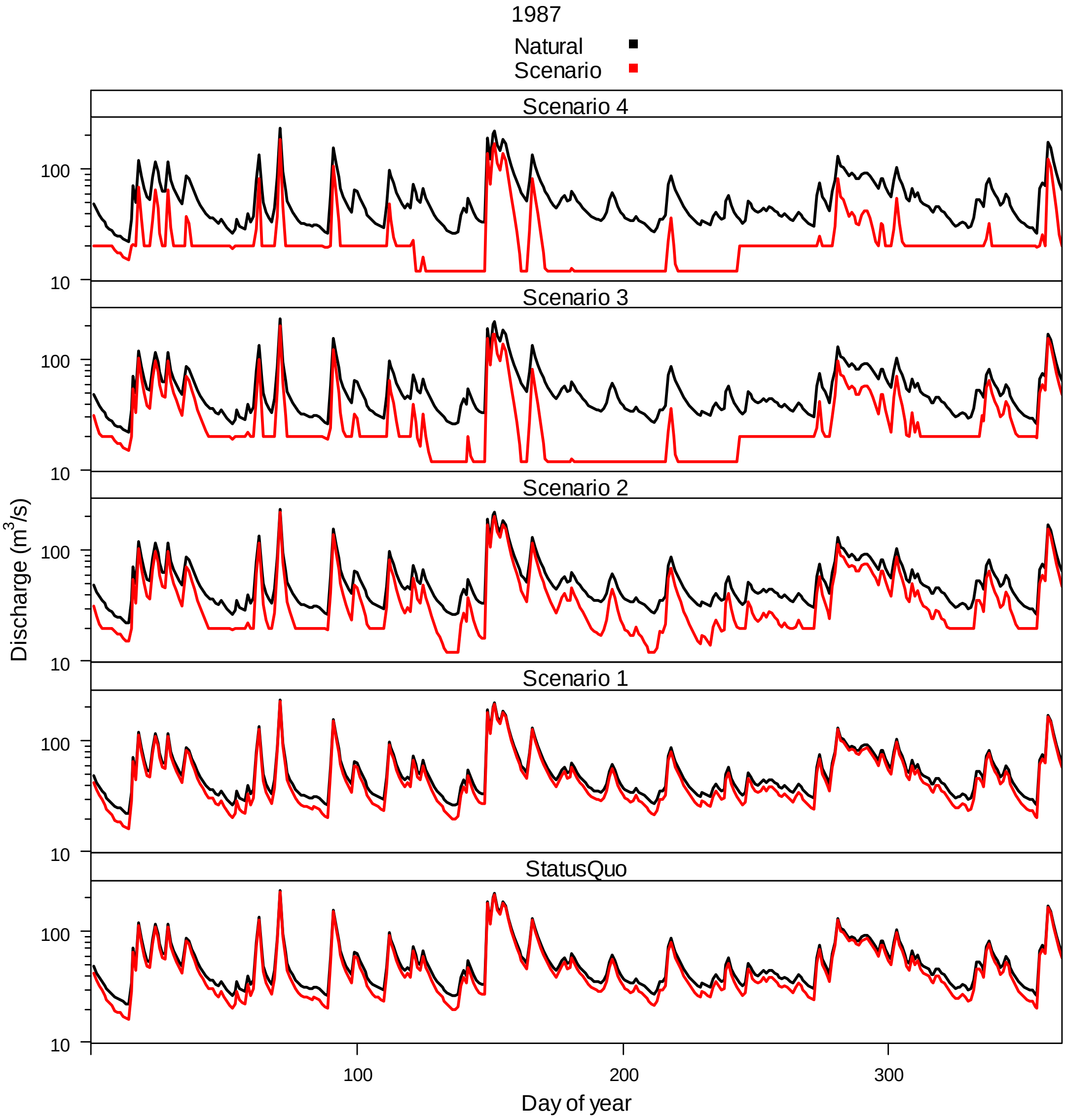


**Figure 4`** **Annual hydrograph for the Waiau River for 1987, which was chosen to represent a typical year. The plots show the natural flow hydrograph (black) and the simulated hydrographs (red) for each of the five allocation scenarios. Note that the vertical axis (discharge) is a log scale.**

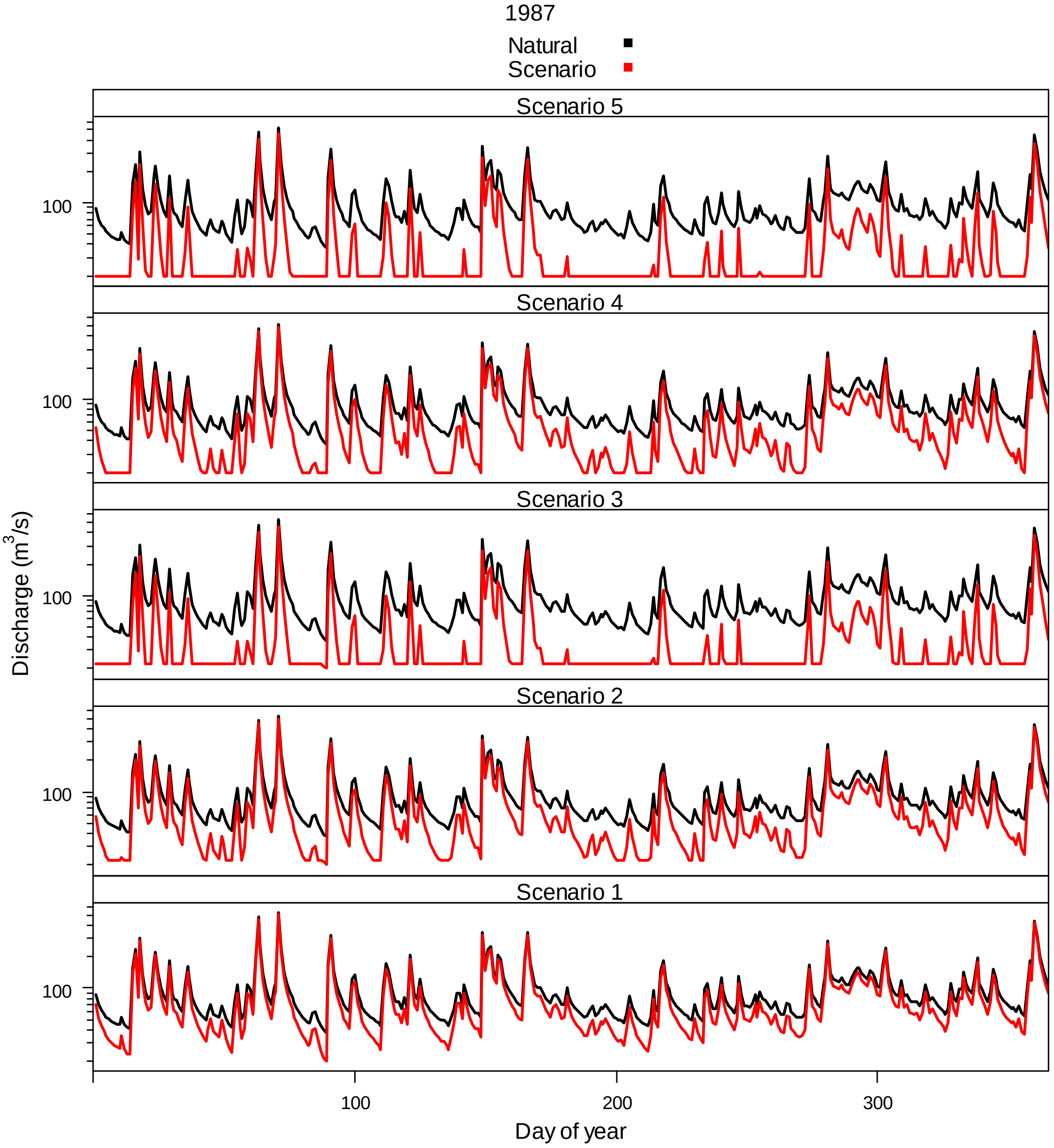


**Figure 5.** **Flow duration curves (FDC) for the Hurunui River at Mandamus constructed from the entire flow time series for the natural flow regime (black lines) and the simulated flow regimes (red lines) for the status quo and the four allocation scenarios.**

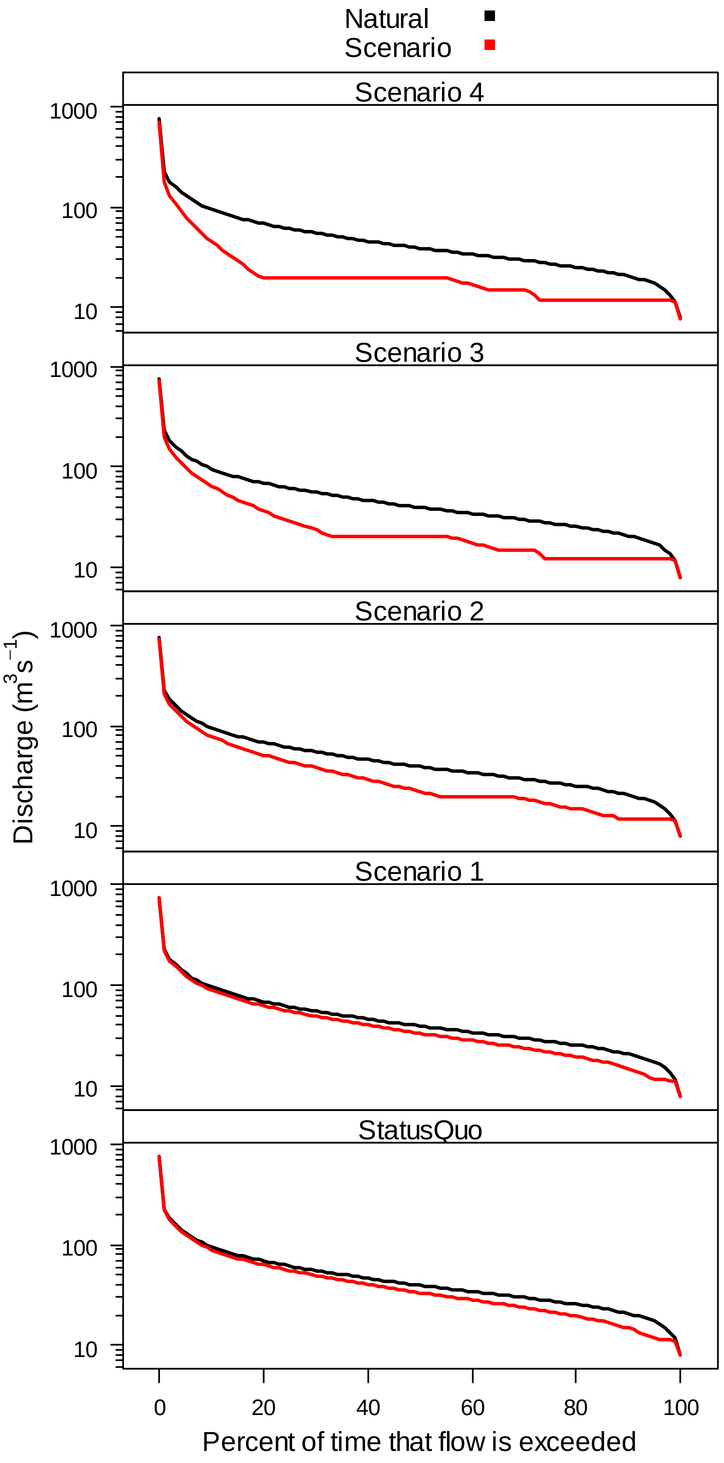
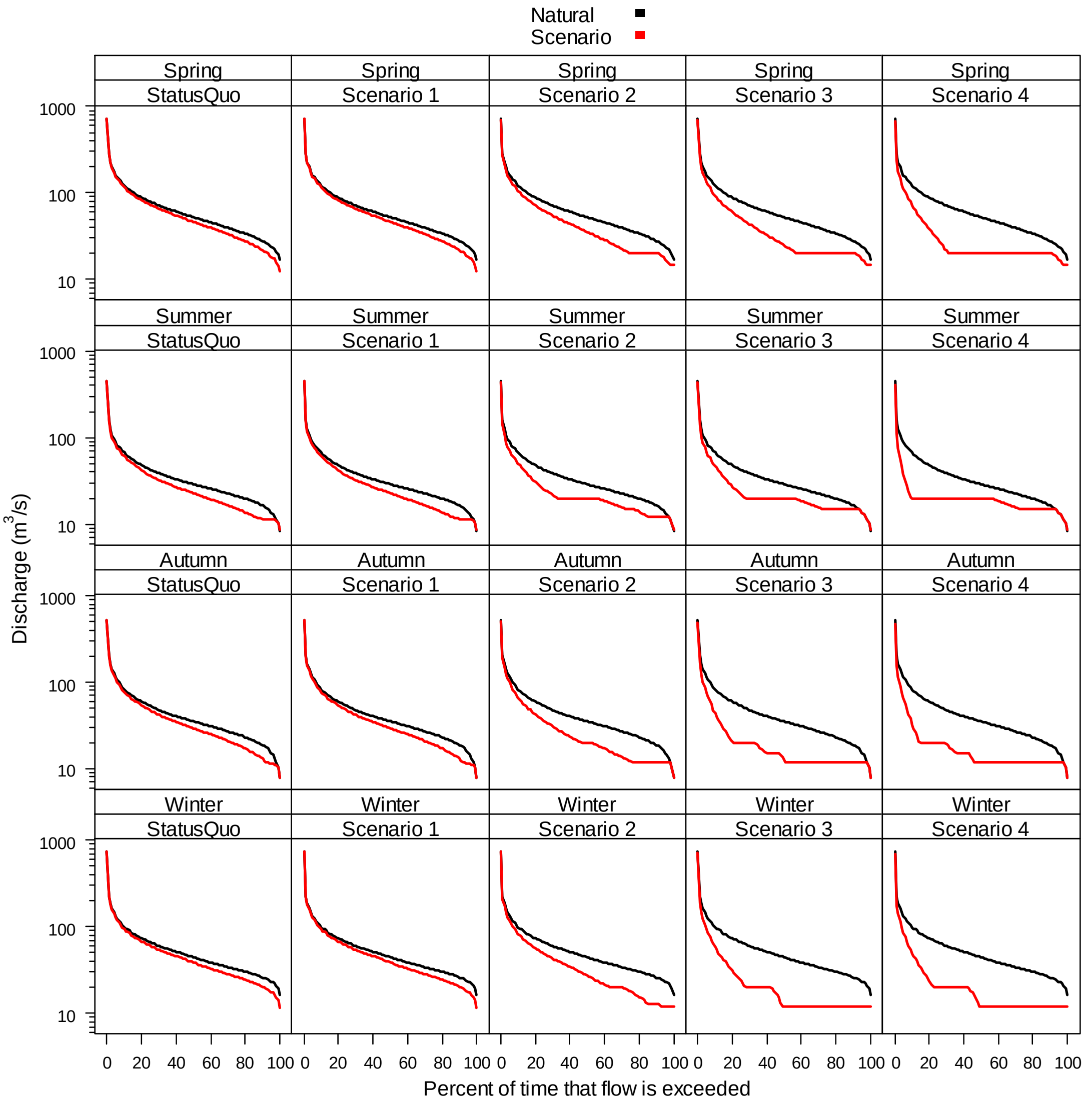


**Figure 6. Flow duration curves for Hurunui at Mandamus in each of four seasons for the natural flow regime, the status quo and the four simulated allocation scenarios. These FDCs were constructed from the entire mean daily flow time series.**



24. My understanding of mid-range flows is that the frequency of high flows and the duration of steady flows (i.e. periods between floods) are associated with at least three important physical and ecological processes:

    i. disturbance of the sediments on the bed of the river;

    ii. flushing of periphyton (and fine sediments) from the river bed; and

    iii. cueing of life-history stages for fish.

25. I have used hydrological indices to quantify changes to i) the frequency of flow events of a specified flow threshold and ii) the duration of periods between events of a specified flow threshold. Hydrological indices summarise time series of flows to characterise particular aspects such as the mean or median flow or frequencies of particular flows. Key indices for assessing the effects of increased allocation are those related to the frequency of floods. A

key question is what flow threshold should be considered to represent a flood. This question is considered in more detail in subsequent sections of my evidence. In this section of my evidence, I compare the change that will occur to nominated indices under the allocation scenarios.

26. The frequency of flood events (events/year) in which a given multiple of the median flow (FREn) is exceeded has been shown by several studies to explain or predict some of the observed variation in periphyton biomass in rivers. The n in FREn represents the multiple of the median flow ($Q_{50}$) that is used to define the flow threshold, for example FRE3 is a flood of three times the median flow. The duration between flow events (days) of a given multiple of the median flow ($DBnQ_{50}$), where n is represents the multiple of the median flow ($Q_{50}$) is related to FREn. Large values of this index represent long periods without floods. I will discuss the importance of this index later and use it to estimate the probability of periphyton cover exceeding nuisance levels.

27. Several of these flow indices are shown in Table 3 for the Hurunui and Waiau rivers for the natural flow regime and the allocation scenarios. For example, FRE3, which for the natural flow regimes of the Hurunui and Waiau Rivers is the frequency of events greater than 219 and 118 $m^3$/s respectively, decreases as the total allocation rate increases (Table 3). Another important result shown in Table 3 is that there is no difference in FRE2 or FRE3 for the Waiau River for: a) scenarios 2 and 4; and b) scenarios 3 and 5. These scenarios have the same total allocations but differ with respect to the gaps between the blocks. Table 3 also shows that the mean duration between events of 2 and 3 times the median flow increases in both rivers as the total allocation increases.

**Table 3. The mean frequency of flow events per year equal to or greater than two (FRE2) and three (FRE3) times the natural median flow and the mean duration between flow events of two ($DB2Q_{50}$) and three ($DB3Q_{50}$) times the median for natural and the simulated flow regimes for the allocation scenarios of the Hurunui and Waiau rivers.**

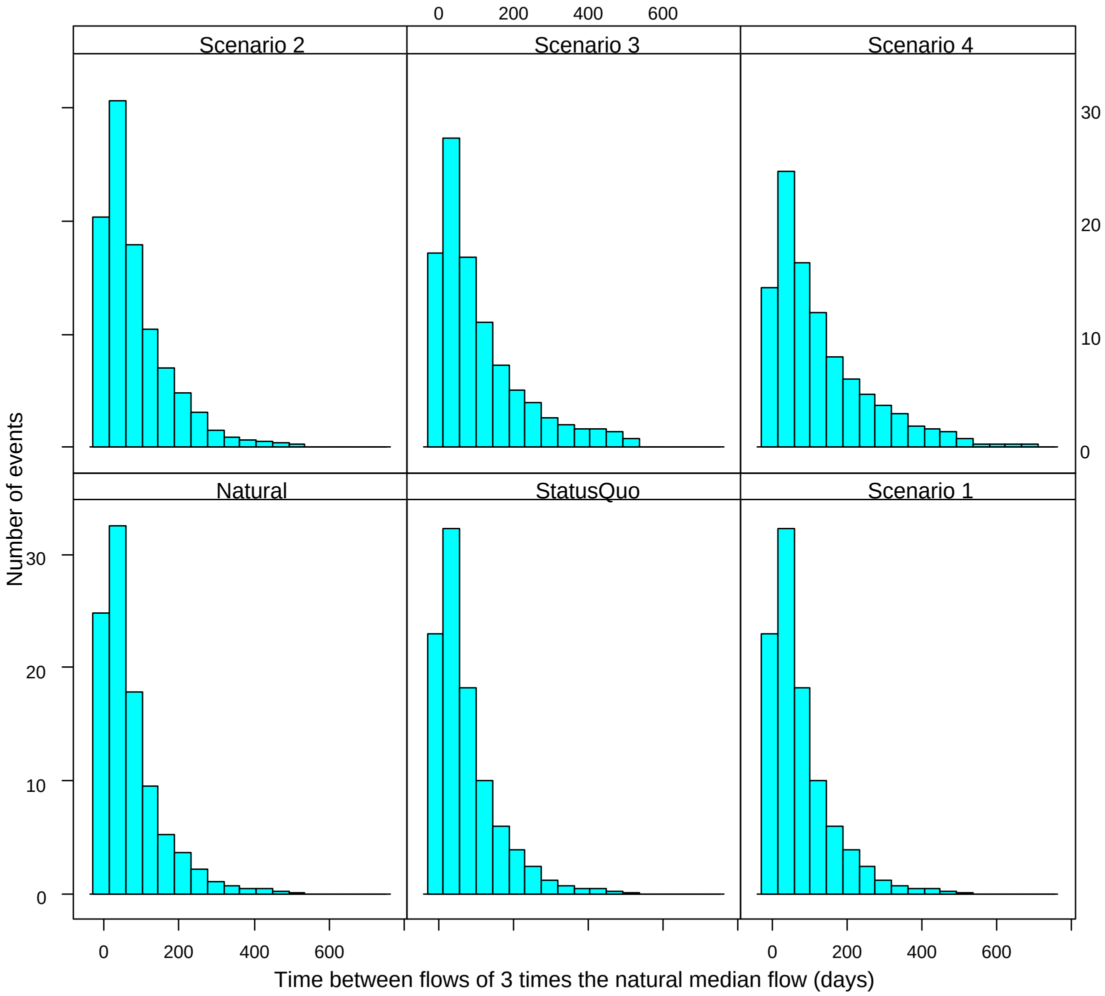
| River | Scenario | FRE2 | FRE3 | $DB2Q_{50}$ | $DB3Q_{50}$ |
|---|---|---|---|---|---|
| Hurunui River | Natural | 8.5 | 5.8 | 33.9 | 68.1 |
| | Status Quo | 8.2 | 5.5 | 37.6 | 71.2 |
| | Scenario 1 | 8.1 | 5.5 | 39.6 | 71.8 |
| | Scenario 2 | 7.1 | 5 | 47.4 | 78 |
| | Scenario 3 | 5.9 | 4.5 | 62.9 | 96.4 |
| | Scenario 4 | 5.3 | 3.9 | 73.7 | 112 |
| Waiau River | Natural | 11.3 | 7.9 | 20.5 | 39 |
| | Scenario 1 | 10.4 | 7.2 | 24.7 | 45 |
| | Scenario 2 | 9.7 | 6.8 | 27.9 | 48.9 |
| | Scenario 3 | 7.9 | 6 | 38.8 | 58.4 |
| | Scenario 4 | 9.7 | 6.9 | 26.9 | 48 |
| | Scenario 5 | 7.9 | 6 | 38.8 | 58.4 |

28. The above analyses indicate that changes to the mid-range flows (from the natural flow) in the Hurunui and Waiau rivers increase as a function of the total allocation. Therefore the greatest changes from the natural flow regime for the Hurunui River are associated with the C-block allocation under

Scenarios 3 and 4. The greatest changes from the natural flow regime for the Waiau River are associated with Scenarios 3 and 5. This is because these scenarios have the largest total allocation rates (71 $m^3/s$).

29. The analyses for the Waiau River indicate that gaps between the allocation blocks would have no impact on the effects to important mid-range flow indices such as the frequency of flood events and the duration between flood events. The analysis shows that the allocation scenarios with the same total allocation will be equivalent in terms of their effects on frequency of flood events and the duration between flood events. This is because significant mid-range flows are higher than the median flow (73 $m^3/s$) and nuances in the manner in which abstraction occurs at flows lower than the median have a negligible effect on the frequency and duration of flood events.

**Figure 7. Histograms showing the frequency distribution of durations between flows of 3 times the median flow (i.e. $DB3Q_{50}$) for the natural flow regime of the Hurunui River at Mandamus and the simulated flows for the five allocation scenarios. The histograms were constructed from the entire mean daily flow time series. Equivalent plots for the Waiau River are provided in Snelder et al. (2011).**



30. The indices shown in Table 3 are the mean number of flow events exceeding thresholds (i.e. FREn) and the mean of the durations between flow events exceeding thresholds (i.e. $DBnQ_{50}$) over the entire flow record. The

distributions of these indices, and how these distributions differ between the scenarios, are also important information for assessing potential effects. For example, the most extreme values of $DBnQ_{50}$ are associated with long periods of stable flows (non-flooding) and may be, therefore, associated with the most significant effects. Histograms can be used to characterise the distribution of these durations. For example, the histogram of the duration $DB3Q_{50}$ for the Hurunui River shows that there are some events that are much longer than the mean duration (Figure 7). In addition, the distributions show that the scenarios with the highest total allocation are associated with more long periods of stable flows (non-flooding) of longer duration, and therefore the highest risk of effects.

# 6. ANALYSIS OF THE IMPACT OF FLOW REGIME CHANGES ON PERIPHYTON IN THE RIVERS

31. In gravel-bed rivers algae growing on the bed (periphyton) is the primary source of food for invertebrate insects, which in turn are food for fish and birds. Periphyton is periodically scoured and flushed from rivers by flows in the mid-range (generally thought to be somewhat higher than the median flow). Higher flows flush periphyton too, but are not as important as mid-range flows because they do not occur as often. If periphyton is not periodically removed its abundance can become excessive. Excessive or ‘nuisance’ growth of periphyton can smother habitat, alter invertebrate communities, produce adverse fluctuations in dissolved oxygen and pH, and impede flows and block water intakes. Excess periphyton can also cause changes to water colour, odour and the general physical nature of the river bed, which has flow-on detrimental effects on aesthetics and human uses.

32. As abstraction rates increase, base flows and the frequency of flows that flush periphyton reduce. Reduced base flows tend to increase the duration of conditions that are conducive for the growth of periphyton and may result in excessive or ‘nuisance’ levels of periphyton abundance. Similarly, reduced frequency of flushing flows may result in an increase in the duration of excessive or ‘nuisance’ levels of periphyton. Changes to periphyton cover downstream of the Opuha Dam in South Canterbury after its commissioning, is evidence that large increases in cover can be expected to arise due to changes to flow regimes and subsequent changes to flow stability and bed material (Lessard et al, in review).

33. The other variables that have important effects on periphyton, and which are affected by human activities, are nutrients. Nutrients, particularly the dissolved oxidised forms of nitrogen (dissolved inorganic nitrate: DIN) and phosphous (dissolved reactive phosphorus; DRP) promote the growth of periphyton and high levels of nutrients can produce excessive or ‘nuisance’ levels of periphyton.

34. I used a simple empirical model of periphyton cover (a measure of periphyton abundance) as a function of antecedent (immediate past) river flows to assess the effect of changes to the flow regime on periphyton. I required long time series of periphyton observations to calibrate my model for the sites of interest (Hurunui River at Mandamus and State Highway 1 and Waiau River at Mouse Point). Suitable monthly periphyton cover (visual estimates) and flow observation have been made for 21 years at 77 National River Water Quality Network (NRWQN) sites throughout New Zealand. Two of these NRWQN sites are on the Hurunui River (Mandamus and State Highway 1).

However, there is no NRWQN site on the Waiau River. CRC have established a short time series of periphyton cover in the Waiau River comprising 86 observations between 2004 and 2010. This time series was not sufficient to calibrate my periphyton model but was useful for characterising the periphyton in the Waiau River. I used two geographically close and environmentally similar NRWQN sites on the Waimakariri River at State Highway 1 and Hurunui River at State Highway 1 as surrogates for the assessment of the Waiau River.

35. The NRWQN periphyton records comprise observations of the proportion of the river bed cover in periphyton in two categories (mats and filaments) at 10 points that are located on the wadeable portion of two transects at each site. River flow is also measured continuously at each NRWQN site.

36. The objectives and policies in the HWRRP that are relevant to my analysis of periphyton are the HWRRP Objective 5.1c and the CRC submission proposed new Policy 5.1, which propose a periphyton biomass <120 mg/m$^2$ and filaments <20% cover in 4 out of 5 years. I was not able to evaluate maximum biomass of periphyton in terms of chlorophyll a (Chl a) because this variable was not measured at the NRWQN or CRC sites. I assessed the observed and modelled periphyton cover against the threshold prescribed by the HWRRP of 20% cover by filaments. To add an additional dimension to my analysis, I evaluated the observed and model periphyton total cover (i.e. mats plus filaments) in terms of using a nominated threshold of 30%.

37. The mean cover by filaments and the mean total cover (mats plus filaments) at all sites were low (Table 4). The HWRRP Objective for cover by filaments was exceeded in the Hurunui at Mandamus and SH1 for 2% and 3% of sample occasions and in 18% and 14% of years (i.e. 0.9 and 0.7 years in 5) respectively. The nominated threshold for mean total cover was exceeded in the Hurunui at Mandamus and SH1 for 5.2% and 8% of sample occasions respectively and in 36% of years (i.e. 1.8 years in 5). The threshold for mean cover by filaments was never exceeded in the Waiua River at SH1 but the threshold for total cover was exceed for 8% of sample occasions and 83% of years (i.e. approximately 4.2 years in 5).

38. The data indicates that neither the Hurunui or Waimakiriri Rivers are entirely appropriate surrogates for the Waiau River. Median concentrations of nutrients at the Waiau River site were more similar to the Hurunui than the Waimakariri (Table 5). However, the mean total cover and the mean cover by filaments at the Waiau River site were more similar to the Waimakariri than the Hurunui (Table 5). The proportion of the time that the mean cover by filamentous algae exceeded the 20% threshold at the Waiau site was more similar to the Waimakariri than the Hurunui site. However, the proportion of the time that the mean total cover exceeded the 30% threshold at the Waiau site was more similar to the Hurunui site than the Waimakariri. These data suggest differences in the periphyton communities between the three sites are not entirely associated with differences in nutrients and flood frequency.

39. There is likely to be physical reasons, other than flood frequency and nutrients, for the differences between to behaviour of periphyton cover at the sites. For example, the Hurunui at State Highway 1 and Waimakariri River at the Gorge have finer and probably more mobile substrates than the Hurunui River at Mandamus site. The presence of Lake Sumner upstream of the latter site has led to a coarsening of the bed material (termed armouring), which

reduces the effectiveness of floods for removing the periphyton and faster regrowth. The coarser bed material may also mean that other processes such as invertebrate grazing may be sustained over a wider range of flows and this may explain why very long accrual times are needed to exceed the thresholds after large floods (Figure 8). Lake Sumner probably affects other factors that influence periphyton such as the quantity of fine material in the water column. These, and probably other factors that influence periphyton, are not well understood and could not be accounted for in the assessment I describe below.

**Table 4. Comparison of the median nutrient concentrations, frequency of flows exceeding two and three times the median flow (FRE2 and FRE3), mean cover and proportion of occasions exceeding two periphyton cover thresholds at the three NRWQN sites and the Waiau River.**

| **Variable** | **Hurunui @ Mandamus** | **Hurunui @ State Highway 1** | **Waimakariri @ Gorge** | **Waiau @ State Highway 1** |
|---|---|---|---|---|
| Median $NO_3$ (mg/l) | 0.013 | 0.277 | 0.061 | 0.22 |
| Median DRP (mg/l) | 0.001 | 0.0026 | 0.002 | 0.0045 |
| Mean cover by filaments (%) | 1.2 | 2 | 0.4 | 0 |
| Mean total cover (mats + filaments) (%) | 5.2 | 6.5 | 2.2 | 1.7 |
| Proportion of occasions (%) exceeding the filament threshold (20%). | 2.0 | 3.0 | 0.4 | 0 |
| Proportion of occasions (%) exceeding total cover threshold (30%). | 5.2 | 8 | 2.3 | 8 |
| Proportion of years (%) in which filament cover threshold (20%) was breached at least once. | 18 | 14 | 5 | 0 |
| Proportion of years (%) in which total cover threshold (30%) was breached at least once. | 36 | 36 | 18 | 83 |

* Based on the Marble Point flow record.

40. My model used the relationship between observations of periphyton cover and time since floods for the NRWQN sites to estimate periphyton cover for the modified flow records that represent the allocation scenarios. The method is described in Appendix A and further details are provided by Snelder et al. (2011). The results of these analyses are summarised as the mean probability of exceeding the periphyton cover thresholds for the both filaments and total cover for the Hurunui and Waiau rivers under all scenarios in Tables 5 to 8.

41. The estimated probabilities of exceeding the thresholds for both filaments and total cover were largest for the Hurunui River for the cover estimates that were based on the periphyton record for NRWQN Hurunui at State Highway 1 site (Tables 5 and 6). For the Hurunui River, the increases in the probabilities of exceeding the thresholds (compared to the natural flow regime) were largest for the State Highway 1 site.

42. For the Waiau River, the estimated probabilities were highest for the analysis that was based on the periphyton record for the NRWQN Hurunui at State Highway 1 site (Tables 7 and 8). However, the increases in the probabilities of exceeding the thresholds for both filaments and total cover (compared to the natural flow regime) were largest for the model based on the Waimakariri River.

**Table 5 Mean probability of exceeding the periphyton cover thresholds (filaments and total cover) for the Hurunui River based on periphyton data for the NRWQN Hurunui at Mandamus site.** TE = Time exceeding threshold (%), ΔTE = Relative increase in time (from status quo) exceeding threshold (%).

| Scenario | TE filaments | ΔTE filaments % | TE total % | ΔTE total % |
|---|---|---|---|---|
| Natural | 1.8 | -5.1 | 6.0 | -4.8 |
| StatusQuo | 1.9 | 0.0 | 6.3 | 0.0 |
| Scenario 1 | 1.9 | 2.1 | 6.3 | 0.8 |
| Scenario 2 | 2.0 | 7.9 | 6.5 | 2.6 |
| Scenario 3 | 2.1 | 10.2 | 6.7 | 5.8 |
| Scenario 4 | 2.0 | 6.4 | 6.3 | 0.5 |

**Table 6 Mean probability of exceeding the periphyton cover thresholds (filaments and total cover) for the Hurunui River based on periphyton data for the NRWQN Hurunui at State Highway 1 site.** TE = Time exceeding threshold (%), ΔTE = Relative increase in time (from status quo) exceeding threshold (%).

| Scenario | TE filaments | ΔTE filaments % | TE total % | ΔTE total % |
|---|---|---|---|---|
| Natural | 3.1 | -8.3 | 8.2 | -4.4 |
| StatusQuo | 3.4 | 0.0 | 8.5 | 0.0 |
| Scenario 1 | 3.5 | 2.1 | 8.6 | 0.2 |
| Scenario 2 | 4.0 | 19.0 | 9.0 | 5.3 |
| Scenario 3 | 4.8 | 42.0 | 9.2 | 8.2 |
| Scenario 4 | 5.3 | 56.9 | 9.3 | 9.2 |

**Table 7 Mean probability of exceeding the periphyton cover thresholds (filaments and total cover) for the Waiau River based on periphyton data for the NRWQN Hurunui at SH1 site.** TE = Time exceeding threshold (%), ΔTE = Relative increase in time (from natural) exceeding threshold (%).

| Scenario | TE filaments | ΔTE filaments % | TE total % | ATE total % |
|---|---|---|---|---|
| Natural | 2.0 | 0 | 7.2 | 0 |
| Scenario 1 | 2.7 | 35 | 7.9 | 10 |
| Scenario 2 | 3.2 | 58 | 8.2 | 13 |
| Scenario 3 | 4.1 | 100 | 8.5 | 18 |
| Scenario 4 | 3.1 | 55 | 8.3 | 15 |
| Scenario5 | 4.1 | 100 | 8.5 | 18 |

**Table 8 Mean probability of exceeding the periphyton cover thresholds (filaments and total cover) for the Waiau River based on periphyton data for the NRWQN Waimakariri at Gorge site.** TE = Time exceeding threshold (%), ΔTE = Relative increase in time (from natural) exceeding threshold (%).

| Scenario | TE filaments | ΔTE filaments % | TE total % | ΔTE total % |
|---|---|---|---|---|
| Natural | 0.3 | 0 | 2.3 | 0 |
| Scenario 1 | 0.4 | 29 | 2.8 | 23 |
| Scenario 2 | 0.5 | 73 | 3.3 | 42 |
| Scenario 3 | 0.9 | 193 | 3.8 | 63 |
| Scenario 4 | 0.5 | 53 | 3.1 | 34 |
| Scenario 5 | 0.9 | 193 | 3.8 | 63 |

43. Based on these analyses, periphyton cover thresholds in the Hurunui and Waiau Rivers will be exceeded more frequently under all allocation scenarios than for the natural flow regime. Under natural flows, the probability of exceeding the filamentous thresholds for the Hurunui River at SH1 and Mandamus was 3.1% and 1.8% respectively. The probability of exceeding the total cover thresholds at these sites under natural flows was estimated to be 8.2 and 6.0 respectively. The probabilities of exceeding the filament thresholds at SH1 and Mandamus sites increased to 5.3% and 2% and for total cover to 9.3% and 6.3% for the allocation scenarios with the largest total allocation.

44. Under natural flows in the Waiau River the probability of exceeding the thresholds was estimated to be low and ranged from 2% to 0.3% of the time for the filamentous cover threshold, and 7.2% to 2.3% of the time for the total cover threshold, depending on whether the Hurunui at SH1 or the Waimakariri rivers respectively were used as the surrogate sites. These probabilities increased to 4.1% and 0.9% for the filamentous cover threshold and 8.5% and 3.8% for the total cover threshold for the allocation scenarios with the largest total allocation (i.e. Scenarios 3, 5 and 6). Table 8 and 9 indicate that there is negligible difference in the estimated probabilities between Scenarios 2 and 4 or between Scenarios 3 and 5. Therefore, the nuances in the manner in which abstraction occurs that are specified by gaps in the scenarios were associated with negligible differences in the estimated effect on periphyton cover.

45. The increases in the probability of exceeding the cover thresholds for both rivers are not large in absolute terms. However, the increases may be considered large in relative terms (i.e. compared to the probabilities of exceeding the threshold under status quo and natural flow conditions). For the Hurunui River, the probabilities of exceeding the filaments and total cover thresholds, relative to the status quo flow probability, increased by 57% and 9% respectively for the model based on the Hurunui at SH1 site. For the Hurunui at Mandamus site, the relative increases were 10.2% and 5.8% (for the Scenario 3). These increased probabilities translate to an increase in the expected number of days exceeding the threshold per year. For example, in the Hurunui at SH 1, model estimates that the filament threshold will be exceeded 3.4% or 12 days per year for the status quo and 3.1% or 11 days per year for the natural flow. The expected days per year that exceed the

filament threshold are estimated to increase to 18 and 19 for Scenarios 3 and 4 respectively.

46. The probability of exceeding the filamentous cover threshold for the Waiau River increased by approximately 50% for Scenario 2 and 4 and more than doubled for Scenario 3 and 5. The increases in probability were therefore larger, in relative terms, for the Waiau than the Hurunui River. However, observations of filamentous cover in the Waiau have never exceeded the guideline (Table 4). It is also noted that the overall reduction in flood frequencies (FRE2 and FRE3) is less in relative terms for the Waiau than the Hurunui River and the frequency of floods greater than 2 and 3 times the median remains higher in the Waiau than the Hurunui River (Table 3). Given this, and because the analysis for the Waiau River was based on surrogate sites, I have less confidence in these estimates. I consider it unlikely that the reduction in flood frequency under Scenario 1, 2 and 4 (Table 3) would produce increases in filamentous cover as large as that predicted by the model.

47. The exceedence of the thresholds for periphyton cover would be experienced by river users and observers as a conspicuous level of green algae adhering to the river bed, extending up into the water column and detaching and becoming entangled in feet, on clothes and limbs while swimming or on equipment used in any recreation activity. The threshold of 20% cover represents a limit at which many people would consider the amount of periphyton to be undesirable (MFE 2000). Increased exceedence of the periphyton cover thresholds would also be likely to be associated with a change in benthic invertebrate community from faunas typifying clean waters to those typically found in organically degraded conditions.

48. Although the model produces estimates of increase in the mean probability of exceeding the periphyton thresholds, these exceedences would not be evenly distributed over all years due to the inter-annual variation in the frequency of floods (Figure 2). This means that long events with nuisance levels of periphyton cover would probably occur in years with particularly low flows. The effect of increased allocation will probably be experienced as an exacerbation of the problems in the years of lowest natural flows, although some increase in the frequency of these events is also likely.

49. I acknowledge that this analysis is subject to a number of uncertainties. First there are a variety of factors that are associated with the growth and removal of periphyton as described above. In this model, only the periods between floods were represented. In addition, estimates of probabilities for some time periods since floods were poor due to insufficient sampling. However, I consider the analysis is a useful estimate of potential changes to periphyton at a site under changing flow conditions.

50. I consider that these estimates are the lower bound on the increases in periphyton cover that could be expected for several reasons.

    i. The analysis only considered the historical pattern of periphyton cover as a function of time between floods. The details of the flows in the between the flood periods were not considered. For the allocation scenarios, the between flood periods would often comprise reduced flow variability compared to the natural flow regime and often in flat-lining. This may create more favourable conditions for periphyton growth than the natural flow regime where some flow variation always occurs between floods.

ii. Changes to sediment size and texture could also affect periphyton cover at the sites and this has not been allowed for in my assessment. Reductions in sediment transport associated with abstraction could potentially increase the size and stability of sediment in a process known as armouring. Armoured beds are less easily mobilised by floods and therefore floods must be larger to achieve the same level of flushing. This would be particularly likely if dams on the main-stems of the rivers were to reduce sediment fluxes in the downstream river channels.

iii. The analysis assumes that nutrient concentrations remain the same. Any increase in nutrients will enhance growth of periphyton. In addition, the combined effect increased nutrients, reduced frequency of floods, greater flow stability (flat-lining) between floods and coarsening of bed material, may produce a multiplicative rather than additive effect on increasing periphyton cover. The evidence of Mr Norton considers the issue of nutrient concentrations in the rivers.

## POTENTIAL MITIGATION MEASURES

51. A final question is whether nuisance growth of periphyton can be mitigated. There are at least three methods that can be used to control periphyton growth; shading, reduction of nutrients and flushing flows. Shading is effective in situations where channels are narrow as stream side plants are able to shade the water surface. However, shading will not be an option in the main stems of the Hurunui and Waiau rivers and many tributaries, which have wide and active beds. Reducing instream nutrient concentrations below the existing level, to compensate for the effect of more favourable flows for periphyton, is also not an option due to the increased irrigation. The use of releases of stored water or delaying the abstraction or diversion of water to storage after extended periods of low flows, can be used to flush periphyton when nuisance growths develop. However, flushing flows would need to be provided for with great care. Releases from dams would need to be very large if they were to be effective in the broad floodplains of the Hurunui and Waiau rivers. In addition, dams would need to be carefully designed to ensure that they were physically capable of generating the required release flow. Investigations of the potential for flushing flows from the Opuha dam has found that the dam is not able to release sufficiently high flows to generate an effective flush (Lessard et al., In review). It is also noted that if bed armouring were to occur, this would be likely to reduce the effectiveness of flushing flows as a mitigation measure.

## 7. CONCLUSIONS

52. My understanding is that the frequency of high flows and the duration of steady flows (i.e. periods between floods) are critical controls on physical and ecological processes in rivers. Changes to flow in the mid-range will occur as total allocation increases and effect are likely due to changes in at least three important processes: disturbance and transport of the sediments on the bed of the river; flushing of periphyton and fine sediments from the river bed; and cueing of life-history stages for fish. In my evidence I have addressed the

potential effects on periphyton cover. Effects of flow regime changes to fish migrations and sediment transport and morphology of the river channels will be discussed by Mr Jellyman and Dr Hicks.

53. The levels of total allocation that could occur in the Hurunui and Waiau Rivers under the HWRRP would significantly change the flow regimes, and in particular, the mid-range flows in the main stems of these rivers. The frequency of small floods could be reduced by more than 30% and the mean duration between floods could increase by more than 50%. In addition, there could be long periods of steady flows (flat lining) between floods.

54. Because many valued aspects of the rivers are dependent to a degree on the mid-range flows, increasing total allocation will be associated with increased risk of failing to meet the Objectives of the HWRRP. In particular, my analysis suggests that, even without changes to water quality, alteration of the flow regimes of the Hurunui and Waiau rivers will lead to an increase in the frequency and duration of exceedence of nuisance levels of periphyton cover. The risk associated with periphyton cover will increase with increasing total allocation and will therefore be most acute in the Hurunui River if the C-block were to be allocated to out of channel use and in the Waiau River if a large B-block were to be allocated.

55. My analysis cannot entirely respond to the question of whether the requirements related to periphyton in the HWRRP will be met because it I was restricted to estimating the probability of exceeding periphyton cover (and not biomass) thresholds. In addition my analysis only estimated probability of exceeding thresholds over all time and not in individual years. There are also uncertainties associated with my analysis that I have discussed above. Therefore, my final conclusions are based on my analysis but also include my subjective judgements.

56. In order to provide simple summary of my findings for periphyton under each of the water allocation scenarios, I have used the ‘scenario evaluation tables’ that are fully described by the evidence of Mr Norton. The scenario evaluation tables are a simple, colour-coded, visual summary that summarise the extent to which I expect the HWRRP objectives and policies will be achieved under each scenario. I have used the same logic in constructing my tables as my colleagues[1] so that the key conclusions from each technical assessment can be easily integrated to provide an overall picture of the consequences of each scenario. In summarising my results I have nominally assigned increases in periphyton cover of less than 10% to the category “Probably”, between 10% and 30% to “possibly” and greater than 30% “unlikely”.

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[1] Ned Norton, Ken Hughey, Ton Snelder, Murray Hicks, Maurice Duncan, Marty Bonnett

**Table 9. Likelihood of achieving HWRRP periphyton outcomes in the Hurunui River at two sites (Mandamus and State Highway 1) under the natural flow regime, status quo and flour flow allocation scenarios. Note that this assessment and summary is based on the assumption that water quality remains as for the status quo. For an analysis of this assumption, and assessment of water quality, see the evidence of Mr Norton.**

| **ACHIEVES…** | **Scenarios…** | | | | | |
|---|---|---|---|---|---|---|
| | **Natural** | **Status Quo** | **Scenario 1** | **Scenario 2** | **Scenario 3** | **Scenario 4** |
| **Periphyton at Mandamus**<br>No increase in the proportion of occasions filaments > 20% cover | Almost Certainly | Probably | Probably | Probably | Possibly | Possibly |
| **Periphyton at SH1**<br>No increase in the proportion of occasions filaments > 20% cover | Almost Certainly | Probably | Probably | Possibly | Unlikely | Unlikely |

**Table 10. Likelihood of achieving HWRRP periphyton outcomes in the Waiau River at Marble Point under the natural flow regime and five flow allocation scenarios. Note that this assessment and summary is based on the assumption that water quality remains as for the status quo. For an analysis of this assumption, and assessment of water quality see the evidence of Mr Norton.**

| ACHIEVES… | Scenarios… | | | | | |
|---|---|---|---|---|---|---|
| | Natural | Scenario1 | Scenario2 | Scenario3 | Scenario4 | Scenario5 |
| **Periphyton at Marble Point**<br>No increase in the proportion of occasions filaments > 20% cover | Almost Certainly | Probably | Possibly | Unlikely | Possibly | Unlikely |

**A H Snelder**

24 September 2012

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MFE 2000. New Zealand Periphyton Guideline: Detecting, Monitoring and Managing Enrichment of Streams. Wellington: Ministry for the Environment.

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# Appendix A Details of periphyton cover analysis

57. Empirical relationships between periphyton cover and time since an effective flood (Da) were developed for two National River Water Quality Network (NRWQN) sites on the Hurunui River (Mandamus and State Highway 1) and the Waiau River using the NRWQN periphyton cover data. Because there are no long term records of periphyton for the Waiau River, two geographically close and environmentally similar NRWQN sites (Waimakariri River at State Highway 1 and Hurunui River at State Highway 1) were used as surrogates to represent the Waiau. These relationships were then used to estimate the effect on periphyton cover of the flow changes under the allocation scenarios in the Hurunui and Waiau rivers.

58. The NRWQN periphyton records comprise 21 years of monthly observations of the proportion of the river bed cover in periphyton in two categories (mats and filaments). Observations are make at 10 points that are located on the wadeable portion of two transects at each site. River flow is also measured continuously at each NRWQN site.

59. The analysis was based on the assumption that counteracting processes (growth and loss) control the amount of periphyton on the river bed. Growth rate is primarily a function of nutrient concentration, but is also dependent on light and temperature. Loss of periphyton biomass is assumed to be primarily a function of floods which remove the periphyton by current drag and associated scouring, abrasion and turning over of bed sediments. Losses may also arise due to invertebrate grazing and sloughing (die-back after growth).

60. In this analysis I made the assumption that loss processes are dominated by floods. Under this assumption, the proportion of the river bed that is covered by periphyton on any particular occasion is a function of the time since an effective flood (i.e. periphyton cover reduced to close to zero). The period since an effective flood is referred to as the accrual period (Da). This assumption is a simplification of reality that was necessary because we have insufficient scientific knowledge to model the effect of other variables involved in determining the cover of periphyton (e.g., invertebrate grazing and sloughing).

61. Periphyton cover was evaluated in terms of the Natural Resources Regional Plan (NRRP) objective for trophic state for alpine (lower) rivers which is a maximum cover of the bed by filamentous periphyton of 20%. A threshold of maximum total cover (i.e. mats plus filaments) of the bed of 30% was also nominated and used in this analysis. I note that the NRRP has an objective for maximum biomass of periphyton of 120 mg $m^{-2}$ chlorophyll a (Chl a). I was not able to evaluate maximum biomass of periphyton because this variable is not measured at NRWQN sites.

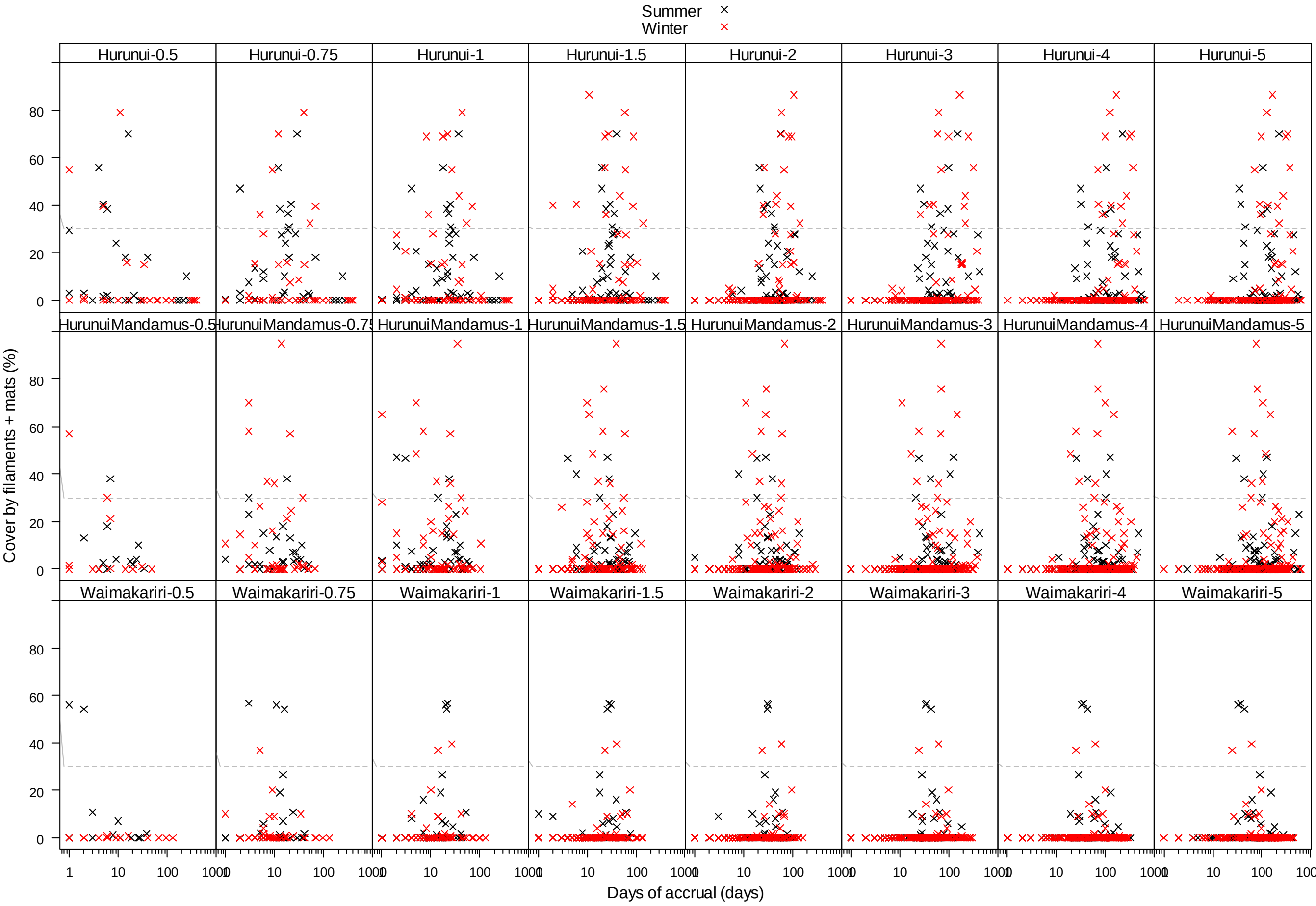
62. The mean periphyton cover on each sampling occasion at the NRWQN sites was calculated by first calculating the mean of the 10 observations of proportion of cover by mats and filaments. The two means (i.e. mats and filaments) were added to define the total periphyton cover. For each periphyton sampling occasion, the accrual time (Da; the time in days since the site had experienced flows of 1, 1.5, 2, 3, 4 and 5 times the median flow), were obtained from the daily flow record.

63. The next step in deriving the periphyton model was to examine the effectiveness of flood events for removing periphyton at the three NRWQN sites by plotting the mean cover on each occasion as a function of Da (Figure 8). The vertical-axis in Figure 8 shows the total cover on each occasion. The cover are the same on all plots, however the horizontal-axis values (Da) for each occasion changes because, in general, for any occasion the time since floods of larger magnitudes is longer than the time since smaller floods.

64. Important observations from the plots are as follows. First, periphyton cover (either filamentous or total) was very low or zero on many occasions irrespective of the value of Da. Second, the minimum accrual period required to reach or exceed any periphyton threshold does not appear to differ by season. Third, when the reference flood flow for computing Da was small (up to 1.5 $Q_{50}$) there were occasions with periphyton mean cover of at least 10% with very short Da (e.g., 3 days; Figure 8). However, at all sites there was only ever very low cover (<10%) for a period of at least 20 days after floods events of three times the median (Figure 8). This observation is interpreted as differences the effectiveness of flood flows of various magnitudes for flushing periphyton from the river bed. There is also significant variation in the observed cover on different occasions with similar Da within sites. These differences are likely due to differences in a range of factors among the sites and between dates within sites. These factors include differences in hydraulic habitat and water physical and chemical properties such as temperature and nutrient concentrations.

65. For the Hurunui sites, floods of at least 2 times the median flow appear to be required to guarantee that the bed will be completely flushed (i.e. the cover was reduced to low levels for a period of at least 20 days). For the Waimakariri site floods of at least 1.5 times the median flow appear to be sufficient to guarantee that the bed will be completely flushed. In general the total cover and cover by filaments was higher for the Hurunui sites than for the Waimakariri. This is likely to be at least partly due to: a) the higher nutrient concentrations at the Hurunui site; b) possibly a reduced supply of fine sediments in the Hurunui, which reduces the effectiveness of flows to remove periphyton by abrasion, and c) differences in the types of periphyton communities at the two sites.

**Figure 8. The relationship between the time in days since floods of various multiples of the median flow and for the proportion of total cover by periphyton (mats + filaments). Data shown are for monthly sample occasions for the period 1989 to 2010 for the three NRWQN sites: Hurunui at State Highway 1, Hurunui at Mandamus and Waimakariri at Gorge. Samples have been coded according to season (Winter (May-September) and Summer (November-April)). The horizontal dashed lines indicate the total periphyton cover threshold of 30%.**



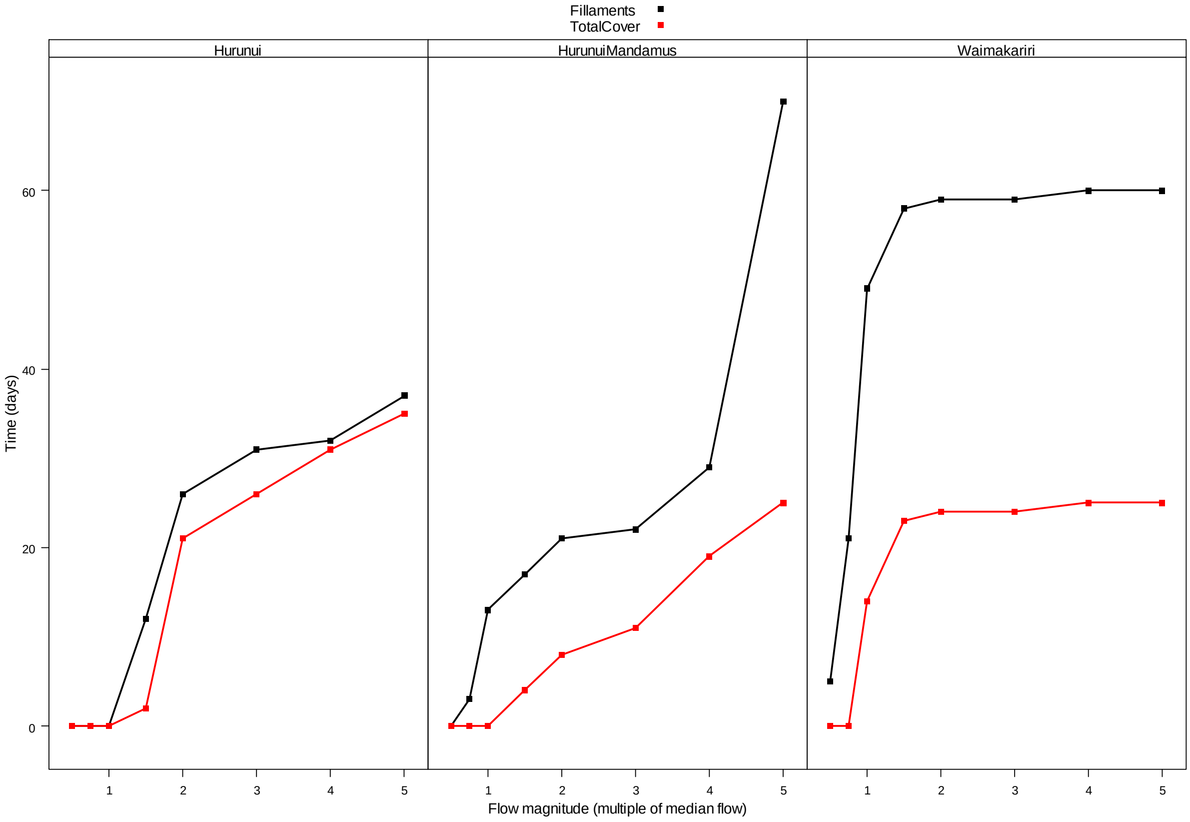
66. The minimum accrual period required before the two periphyton thresholds were exceeded (i.e. 20% for filaments and 30% for total cover) was quantified by determining the minimum time between any flood (Da) and subsequent exceedance of a periphyton threshold. These minimum times are shown for the full range of reference flows in .

67. Figure 9. The plots indicate that the minimum accrual period required to exceed a threshold increased with the size of the preceding flood event. For the Hurunui at State Highway 1 site there were large increases in the minimum accrual period required to exceed a threshold between flood events of 0.25 to 1.5 times the median flow. For flood events larger than 2 times the median flow the accrual period required to exceed the periphyton cover thresholds increased by only a small amount. For the Hurunui at Mandamus site there were large increases in the minimum accrual period required to exceed a threshold between flood events of 0.25 to 1 times the median flow. For flood events larger than 2 times the median flow the accrual period required to exceed the periphyton cover thresholds increased by a large amount, indicating that some process, other than floods, may be limiting the peak cover at this site when accrual periods are very long. For the Waimakariri site there were large increases in the minimum accrual period

required to exceed a threshold between flood events of 0.25 to the median flow. For flood events larger than 1.5 times the median flow the accrual period required to exceed the periphyton cover thresholds increased by only a small amount.

68. There are several potential reasons for the observed differences in minimum accrual periods between the sites. First, the proportion of occasions in which the periphyton cover thresholds were exceeded was very low in the Waimakariri River (Figure 8). Thus, the relationship between accrual period required to exceed the periphyton cover thresholds and flood event size may be poorly estimated from these data. Second, the relationship between flow and bed disturbance may be different at the sites, with lower flows required to generate the equivalent reduction in cover in the Waimakariri River. Third, differences in the periphyton communities at the two sites may be associated with differing levels of resistance to disturbance and different responses to stable flows. For example, the bed sediment at the Hurunui at Mandamus site is larger and more stable than at the other sites as a result of the relatively lower sediment flux due to the upstream Lake Sumner.

**Figure 9. Minimum time (Da) to exceed periphyton thresholds at the three NRWQN sites since flood events of several magnitudes as referenced by multiples of the median flow at each site.**



69. The next step in the analysis was to estimate the probability of exceeding periphyton thresholds given Da, where Da was the time since flood events of two nominated magnitudes. Two flow thresholds were nominated because a range of flood flows will remove periphyton. This observation is consistent with the bed movement analysis (evidence of Mr Maurice Duncan), which shows that a degree of flushing (and periphyton removal) occurs over the entire flow range. I used the time since two reasonably effective flood flows in

my model to better cover the range of flood flow events that may explain the periphyton cover on each sampling occasion. The use of this “bi-variate” approach to estimating the probabilities of exceeding periphyton thresholds is still a simplification of what is in reality a continuous relationship between antecedent flows and cover. However, the bi-variate approach captures information about the “nested” nature of accrual periods as defined by times since floods of various magnitudes. For example, for some sampling occasions there may have been a long accrual period since a flood of a high threshold, but there may have also been a slightly smaller, though nevertheless effective, flood that removed cover immediately before sampling. The bivariate approach to estimating periphyton cover helps to represent this situation. Flood event magnitudes of 2 and 3 times the median flow were nominated for the Hurunui River sites because larger floods do not greatly increase the time to exceed the thresholds and because smaller floods were not effective for flushing (Figure 9). For the same reasons, for the model based on the Waimakariri River data, we nominated flood event magnitudes of 1.5 and 2 times the median flow.

70. The days of accrual (Da), calculated for flood events of both flood event thresholds, was subdivided into intervals bounded by 0, 5, 10, 25, 50, 100, and 450 days. The proportion of samples that exceeded the periphyton thresholds were counted for every combination of these Da intervals. The resulting analysis was expressed as matrices in which each cell is the probability of exceeding the threshold depending on the flow history expressed as Da. An example of these matrices is shown in Table 9 and more details are presented in Snelder et al (2011).

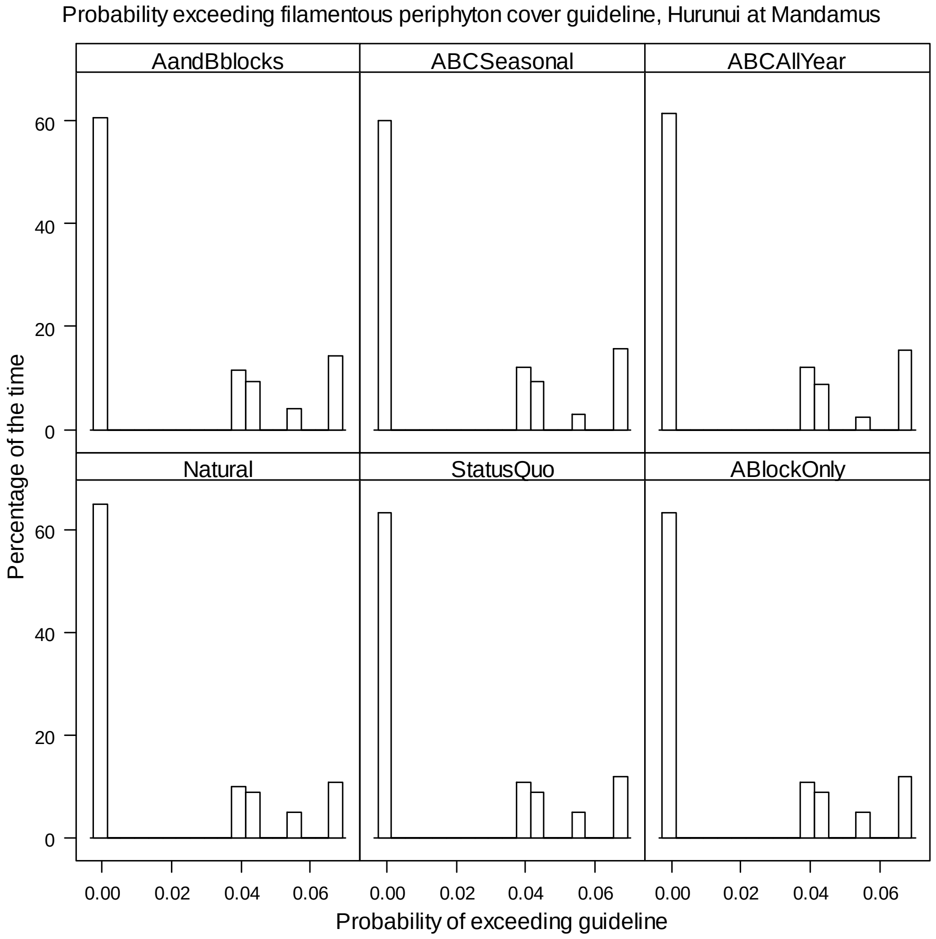
**Table 9. The probabilities of exceeding the threshold for filamentous periphyton cover and total cover (mats + filaments) given Da (defined by flows of 2 and 3 times the median) and counts of observations (from which the probabilities were estimated) for the Hurunui at Mandamus site.**

| | | Da 3 | | | | | |
|---|---|---|---|---|---|---|---|
| | **Da 2** | **0-5** | **5-10** | **10-25** | **25-50** | **50-100** | **100-450** |
| Filamentous cover | 0-5 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 5-10 | NA | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 10-25 | NA | NA | 0.00 | 0.00 | 0.00 | 0.00 |
| | 25-50 | NA | NA | NA | 0.04 | 0.00 | 0.20 |
| | 50-100 | NA | NA | NA | NA | 0.10 | 0.06 |
| | 100-450 | NA | NA | NA | NA | NA | 0.08 |
| Total cover | 0-5 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5-10 | NA | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 10-25 | NA | NA | 0.00 | 0.43 | 0.09 | 0.00 |
| | 25-50 | NA | NA | NA | 0.12 | 0.15 | 0.30 |
| | 50-100 | NA | NA | NA | NA | 0.14 | 0.18 |
| | 100-450 | NA | NA | NA | NA | NA | 0.08 |
| Counts | 0-5 | 34 | 18 | 2 | 9 | 5 | 6 |
| | 5-10 | NA | 6 | 8 | 4 | 1 | 2 |
| | 10-25 | NA | NA | 21 | 7 | 11 | 4 |
| | 25-50 | NA | NA | NA | 25 | 13 | 10 |
| | 50-100 | NA | NA | NA | NA | 30 | 17 |
| | 100-450 | NA | NA | NA | NA | NA | 26 |

71. At the final step, the time-series of natural and simulated residual flows for the Hurunui and Waiau rivers were combined with the estimated probabilities of exceeding the threshold as a function of Da (e.g., Table 9). For each time step (i.e. each day) of each time-series, we evaluated Da for the two flow thresholds for each model site (i.e. 2 and 3 times the median flow for the Hurunui River sites and 1.5 and 2 times the median flow for the Waimakariri River). For each time step we then obtained the probability of exceeding the cover threshold for each site, each scenario and both periphyton types (i.e. filamentous and total). This produced daily time-series of probabilities that the thresholds would be exceeded for each site, scenario and periphyton type.

72. A plot showing the distribution of the probabilities of exceeding the filamentous cover threshold for all scenarios for the Hurunui at Mandamus site is shown in Figure 10. The distributions show that, for all scenarios, the majority of days have zero probability of exceeding the thresholds (hence the large left-most bar in the plots shown in Figure 10). As the total allocation increases under the scenarios, the number of days with a zero probability of exceeding the threshold decreases. In addition, as total allocation increases, the number of days with higher probabilities of exceeding the thresholds increases. More details for the Waiau River are presented in Snelder et al (2011).

**Figure 10. The results of applying the estimated probability of exceeding the threshold for total periphyton cover given Da referenced by 2 and 3 times the median flow for the Hurunui at Mandamus site (i.e. Table 9) to the simulated flow time series representing the natural and allocation scenarios.**



73. The final step was to obtain the average probability over the entire time series for each site, scenario and periphyton cover type (i.e. filamentous and total). These results are summarized in Tables 5, 6, 7 and 8. The results indicate that the probability of exceeding the threshold is lowest for the natural flow and increases with the allocation scenarios.