# Assessment of effects of increased nutrient concentrations due to catchment land use changes in the Hakataramea River

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# Assessment of effects of increased nutrient concentrations due to catchment land use changes in the Hakataramea River

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# Summary


*Background*

This work examines the effect of increased nutrient concentrations on the Hakataramea River resulting from potential changes in agricultural land use and management practices (irrigation). Generally, rivers may be nutrient enriched due to non-point sources resulting from agricultural land use, particularly when irrigation runoff and discharge to groundwater occurs. The main objective of this work is to assess whether three potential future land use scenarios could lead to adverse effects on the Hakataramea River, specifically by increasing nuisance growths of periphyton, phytoplankton and/or macrophytes. Excessive growths can be a nuisance for a number of reasons. They may degrade habitat conditions and water quality conditions for aquatic invertebrates and fish, reduce visual and aesthetic values, and restrict recreation opportunities such as angling.

Scenario 1 is the existing case. Scenario 2 assumes all new water take consent applications currently applied for are granted. Scenario 3 assumes implementation of a community irrigation scheme. Scenario 4 assumes that all existing and future irrigable land is converted to dryland sheep production.

*Methods*

This report builds on the results of two earlier reports that have been produced specifically for this purpose. The earlier reports provided quantitative estimates of the impacts of existing land-use and three potential land use scenarios on groundwater nitrate loads (Zemansky et al. 2006) and phosphorus loads (McDowell 2006). We have used the outputs from these reports to assess the likely effects on the water quality and habitat conditions of the Hakataramea River. The methods and results are presented, together with a discussion of the assumptions and the rationale for the analytical approach used. We used the estimates of nitrogen and phosphorus loads provided by Zemansky et al. (2006) and McDowell (2006) to estimate in-river concentrations of dissolved inorganic nitrogen (DIN) and dissolved reactive phosphorus (DRP). We then applied generalised relationships between nutrient concentrations, the frequency of river flood events and periphyton biomass, to predict periphyton biomass under existing conditions and each of the three potential land use scenarios. We then used the New Zealand periphyton guidelines to estimate the likely ecological effects of the predicted periphyton biomass for each scenario.

*Key results*

The assessment indicates that the Hakataramea River currently exceeds at times all of the New Zealand Periphyton Guideline maximum biomass criteria for protecting visual aesthetic, benthic biodiversity, trout habitat and angling values. Periphyton biomass predictions for the existing land-use situation were about double the highest guideline criteria. Predictions indicate that if new water take consents were granted to all of those who have applied, except for the storage based community scheme (scenario 2), this could increase algal biomass in the Hakataramea River by about 20% over the existing situation. Irrigation on a community scheme scale (scenario 3) could increase algal

biomass by about 60% over the existing situation. If all existing irrigated land and all potentially irrigable land in the catchment was converted to dryland sheep production (scenario 4), this could reduce algal biomass by about half from the existing situation.

*Assumptions and biases*

The predictions in this report have been based on a number of assumptions, some of which may lead to over-estimates of periphyton biomass while some may under-estimate biomass. Overall, the predictions are best considered as 'average' annual maximum biomass predictions - under different climate and physical habitat conditions the actual periphyton biomass observed can be expected to vary widely in both space and in time, being at times worse and at times better than predictions. The biomass predictions for the existing situation have been corroborated to some extent by actual biomass measurements and observations of periphyton blooms in the River in recent years. We consider these to be best estimates based on available data and methodology.

*Conclusions*

- Periphyton blooms that breach the New Zealand Periphyton Guidelines occur periodically in the Hakataramea River under the existing conditions. Current water abstraction is a contributor to this situation due to water use for irrigation leading to more intensive land use and lower flows in the river.

- Future land use intensification is likely to cause further breaches in the Guidelines, by increasing the nutrient loading and increasing water takes, leading to further changes in algae biomass and trophic state in the Hakataramea River. This could decrease the value of the River in terms of aesthetic, aquatic ecology, trout habitat and angling values.

- Whether these changes are acceptable is outside the scope of this report and will depend on the objectives for management in this catchment. The Proposed Natural Resources Regional Plan (PNRRP) has set water quality outcomes for this catchment.

- There are a suite of best land management practices (BMPs) that can potentially reduce nutrient losses from land to groundwater and rivers. Some examples are listed in this report. The effectiveness of these methods varies widely with quality of design and care in implementation, and will also be strongly influenced by nutrient loading rates and local conditions such as soils, climate, time-scale, and topography.

- We also note that *Didymosphenia geminata* (didymo), an invasive alga that became established in the lower Waitaki River in 2006, is not currently present in the Hakataramea catchment. If didymo did become established it would be likely to grow to biomass levels that exceed the New Zealand Periphyton Guideline thresholds under all scenarios.

# 1. Introduction

This work examines the effect of increased nutrient concentrations on the Hakataramea River resulting from potential changes in agricultural land use and increased irrigation. In general, rivers may be nutrient-enriched from intensive agricultural land uses, particularly when irrigation runoff and discharge to groundwater occurs. The main objective of this work is to assess whether future irrigated land use and management changes could lead to adverse ecological effects on the Hakataramea River, specifically nuisance growths of periphyton, phytoplankton and/or macrophytes.

Some increase in nutrient concentrations may be acceptable and result in little change to the river ecosystem or its valued resources. However, excess concentrations of nutrients may adversely affect values by promoting development of high algal biomass. Excessive algal biomass can adversely affect fish and invertebrate communities by smothering riverbed habitat and may cause excessive fluctuations in dissolved oxygen and pH levels caused by plant respiration. Excessive algal cover in rivers also has social and human use effects such as reduced recreational and aesthetic quality (Biggs 2000; MfE 2000). Management of river nutrient concentrations is a broad-scale management issue.

This report describes the methods used to assess the likely changes to algae biomass in the Hakataramea River, due to increased nutrient loads under different future land use scenarios. Those scenarios are:

- Scenario 1 – Existing irrigated land uses (from currently consented activities).
- Scenario 2 – Irrigation at a level considered economically viable for irrigation at this time (if new consents were to be granted to all of those who have applied with the exception of the storage based community scheme).
- Scenario 3 – Irrigation of all potentially irrigable land in the catchment (defined as the community storage scheme plus existing irrigated land that falls outside the community scheme area).
- Scenario 4 – Fully dry land without any irrigation. Assumes dryland sheep conditions on all the land identified for scenario 3, including land currently irrigated.

This report builds on the results from earlier reports that have been produced by others specifically for this study. In brief the earlier reports are:

i) Potential impacts of irrigation on groundwater nitrate in the Hakataramea River catchment (Zemansky et al., 2006). This report assessed irrigation impacts on nitrogen in groundwater, and modelled annual loads of nitrogen within the catchment for the existing irrigated land uses and the same three potential land use scenarios listed above.

ii) Estimation of phosphorus loads from dryland and irrigation areas in the Hakataramea catchment (McDowell 2006). This report assessed irrigation impacts on phosphorus loads within the catchment for the existing irrigated land uses and the same three potential land use scenarios listed above.

The outputs from these reports have been used in an analysis for the Hakataramea River as described below.

# 2. Methods and results

## 2.1. Method overview

The method involved several steps. First we used the estimates of annual nitrogen and phosphorus losses from the four land-use scenarios provided by Zemansky et al. (2006) and McDowell (2006) to estimate in-river concentrations of dissolved inorganic nitrogen (DIN) and dissolved reactive phosphorus (DRP). Next we applied generalised relationships between nutrient concentrations, the frequency of river flood events and periphyton biomass, from New Zealand science literature (Biggs 2000), to predict periphyton biomass under existing conditions and each of the three potential land use scenarios. We then used the New Zealand periphyton guidelines (MfE 2000) to estimate the likely aquatic ecological effects of the predicted periphyton biomass for each scenario. Detail on each of these steps is provided below.

## 2.2. Modelled annual nutrient losses

The methods used in this report rely on annual loads of nitrogen and phosphorus that have been modelled for the existing irrigated land uses and the three potential land use intensification scenarios by Zemansky et al. (2006) and McDowell (2006) respectively. Both of these models divided the catchment into two zones, upper and lower catchment, based on a boundary at Wright's Crossing. Results were provided by these authors as annual loads of nitrogen and phosphorus (in kg/ha/year) for the upper, lower, and combined catchment under each scenario. For the purpose of estimating in-river nutrient concentrations and periphyton biomass, we have selected two assessment sites: the Hakataramea at Wright's Crossing; and the Hakataramea at the

Hakataramea Bridge (MHBr). These sites receive annual nutrient loads predicted by Zemansky et al. (2006) and McDowell (2006) for the upper catchment, and the combined lower plus upper catchments respectively.

## 2.3. Estimating in-river concentrations of dissolved nutrients

Mean flow for the Hakataramea River at MHBr was derived from measured data at the main highway bridge, and a mean flow value for Wright's Crossing was taken from the nitrogen modelling work (Zemansky et al. 2006). The modelled annual nitrogen and phosphorus loads were converted to mean concentrations of dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DRP) by dividing the annual mass of each nutrient by the estimated mean river flow (Table 1). Two assumptions have been made with the nitrogen modelling data. First, DIN has been calculated directly from nitrate loads (i.e. without ammonia or nitrite inputs) - this is assumed to be a reasonable assumption because nitrate normally represents the dominant form of nitrogen contribution to DIN. Second, all nitrate entering groundwater, as calculated by Zemansky et al. (2006), is available to enter the Hakataramea river flow. The first assumption is likely to underestimate DIN; the second to overestimate.

## 2.4. Estimating river flood frequency (FRE3)

River flood frequency was calculated from the measured data at the main highway bridge using FRE3 (the mean number of flood events per year that exceed three times the median flow). FRE3 was estimated from daily mean flow records, using a 7-day filter period[1] (Table 1). In the absence of a long-term flow record in the upper catchment (i.e., near or above Wright's Crossing) FRE3 has been assumed to be the same at Wright's Crossing as it is at the main highway bridge for the purposes of modelling the upper and lower catchment outputs.

## 2.5. Estimating periphyton biomass

Average annual maximum algae biomass in the river at each assessment location was estimated using the model of Biggs (2000). This model assumes that algae biomass in gravel bed rivers is a function of the counteracting processes of resource supply (required for growth) and biomass loss. Growth rate is determined primarily by

[1] We have used the term *filter period* to describe the period within which flow counts exceeding three times the median flow have been counted as one flood event.

**Table 1:** Data used for the assessment. Mean flow and FRE3 (the mean number of flood events per year that exceed three times the median flow) have been established from flow data for the Hakataramea. DIN and DRP concentrations are those based on annual loads estimated by Zemansky et al. (2006) and McDowell (2006) respectively, converted to annual average concentrations at the two assessment sites (Wright's Crossing and Hakataramea Bridge (MHBr)) using mean river flow at those sites. [Note that the estimated concentrations represent an average case in that they are based on mean annual flow. They do not represent the maximum (worst case) concentrations which would be likely to occur during times of lowest river flow and highest nutrient losses – this would be most likely to occur during the summer irrigation season - see Section 3 for discussion of assumptions and biases].

| Assessment Site | Hakataramea at Wright's Crossing | | Hakataramea at MHBR | |
|---|---|---|---|---|
| FRE3 | 5.86 | | 5.86 | |
| Mean flow ($m^3$/s) | 4.802 | | 5.743 | |
| | (Based on upper catchment loads) | | (Based on combined upper & lower catchment loads) | |
| | DIN (mg/$m^3$) | DRP(mg/$m^3$) | DIN (mg/$m^3$) | DRP (mg/$m^3$) |
| Scenario 1 (existing) | 337.0 | 2.3 | 586.3 | 5.1 |
| Scenario 2 | 610.1 | 4.5 | 846.5 | 7.2 |
| Scenario 3 | 2502.8 | 12.8 | 2963.3 | 13.9 |
| Scenario 4 | 415.7 | 1.0 | 489.5 | 1.1 |

nutrient supply and light, and biomass loss is determined by hydrological disturbance (i.e., velocity increase and substrate movement during flood flows) and invertebrate grazing. Past studies have shown that the Biggs (2000) model can account for over 70% of the variability in maximum algal biomass using mean monthly DIN and DRP and 'days of accrual', which is the time between flood events that significantly increases velocity and removes algae (Biggs 2000).

The New Zealand Periphyton Guideline (MfE 2000) uses Biggs' (2000) model to define nutrient concentration criteria for rivers based on yearly maximum algae biomass. In the Hakataramea River assessment, the equations have been used to assess the biomass (as chlorophyll *a* in mg $m^{-2}$) that could arise from the existing and proposed land use scenarios, based on the estimated nutrient concentrations and the calculated indicator of flood disturbance FRE3 (Table 1).

Equations (1) and (2) from MfE (2000) provide a prediction of yearly maximum benthic algae biomass.

$$\text{Log}_{10}\,(\text{maximum chl. a}) = 4.716\,(\log_{10} \text{Da}) - 1.076\,(\log_{10} \text{Da})^2 + (0.494\,\text{Log}_{10}\,\text{DRP}) - 2.741 \qquad (1)$$

$$\text{Log}_{10}\,(\text{maximum chl. a}) = 4.285\,(\log_{10} \text{Da}) - 0.929\,(\log_{10} \text{Da})^2 + (0.504\,\text{Log}_{10}\,\text{DIN}) - 2.946 \qquad (2)$$

Yearly average-maximum algal biomass was estimated using Equations 1 and 2 and the modelled nutrient concentrations at each assessment location for each scenario (Table 1). In Equation 1 and 2 the days of accrual (Da) is the average time between significant floods and is measured using the flow statistic FRE3. Da is based on the following equation:

$$\text{Da} = \frac{1}{FRE3} \times 365.25 \qquad (3)$$

Equations 1 and 2 allow calculation of estimates of algal biomass based on whether DIN or DRP respectively is the limiting nutrient for growth. Usually one of these two nutrients is in shorter supply than the other nutrient and thus limits algal growth (all other things being equal). Predicted algal biomass (average annual maximum chlorophyll *a*) calculated using phosphorus as the limiting nutrient is shown in Table 2. Predicted algal biomass based on nitrogen as the limiting nutrient is shown in Table 3. Predictions based on phosphorus as the limiting nutrient (Table 2) yield the smaller algal biomass and these numbers are therefore likely to be a better prediction of actual effects than those in Table 3. This is because the biomass predicted in Table 3 is unlikely to occur due to phosphorus limitation, as we discuss further in Section 2.6 below.

**Table 2:** Predicted average annual maximum chlorophyll *a* (mg $m^{-2}$) at assessment sites, based on modelled DRP (Equation 1).

| | At Wright's Crossing<br><br>Average annual maximum Chl *a* (DRP) | At Hakataramea Bridge (MHBr)<br><br>Average annual maximum Chl *a* (DRP) |
|---|---|---|
| **Scenario 1** | 273 | 403 |
| **Scenario 2** | 379 | 481 |
| **Scenario 3** | 635 | 662 |
| **Scenario 4** | 182 | 188 |

**Table 3:** Predicted average annual maximum chlorophyll *a* (mg $m^{-2}$) at assessment sites, based on modelled DIN (Equation 2).

| | At Wright's Crossing<br><br>Average annual maximum Chl *a* (DIN) | At Hakataramea Bridge (MHBr)<br><br>Average annual maximum Chl *a* (DIN) |
|---|---|---|
| **Scenario 1** | 1062 | 1403 |
| **Scenario 2** | 1432 | 1689 |
| **Scenario 3** | 2916 | 3175 |
| **Scenario 4** | 1180 | 1281 |

Predicted algal biomass is highest under scenario 3 (the irrigated community scheme) at both of the Hakataramea River sites (Table 2). Irrigation on a community scheme scale (scenario 3) could increase the average annual maximum biomass from 403 mg $m^{-2}$ to 662 mg $m^{-2}$, i.e., by more than one and a half times or about a 60% increase over the existing situation. If new water take consents were to be granted to all of those who have applied for consents, except the storage based community scheme (scenario 2), this could increase the average annual maximum biomass from 403 mg $m^{-2}$ to 481 mg $m^{-2}$, i.e., about a 20% increase over the existing situation. If all existing irrigated land and all potentially irrigable land in the catchment was converted to dryland sheep production (scenario 4), this would reduce predicted average annual maximum biomass, compared to the existing situation (scenario 1), from 403 mg $m^{-2}$ to 188 mg $m^{-2}$ (i.e., by about half).

## 2.6. Estimating which nutrient limits growth

We used two methods to indicate which nutrient is likely to limit periphyton growth:

*i) Assessment of measured nitrogen to phosphorus ratios*

Nitrogen to phosphorus ratios below 30 are usually associated with nitrogen limitation of algae growth while ratios of greater than 30 are usually associated with phosphorus limitation (Biggs 2000). In most cases the existing data and scenario estimates for ratios of DIN to DRP far exceed 30 to 1. Thus, based on DIN:DRP ratios we would predict phosphorus to be the limiting nutrient for most of the time, as already indicated by the smaller predicted algal biomass based on predicted phosphorus concentrations (Table 2) than biomass predictions based on nitrogen concentrations (Table 3).

*ii) River nutrient (in situ) bioassays.*

River nutrient bioassays conducted *in situ* are a more direct way to estimate nutrient limitation at a site of interest (Wilcock et al. 2007). We carried out a bioassay at a site on the Hakataramea River 200 m upstream of the Bridge (MHBr). The bioassay was performed following the steel-tray nutrient diffusing substrate method (NDS) described in Biggs and Kilroy (2000). Phosphorus and nitrogen availability were manipulated in a two-way factorial design (2 × 2 × 5 replicates = 20 units per experiment), which results in four treatments: no nutrients (control), nitrogen only added (+N), phosphorus only (+P) and both nitrogen and phosphorus added (+N&P). The bioassay plate was left in the river for the first three weeks in March 2007, after which time the treatments were sampled for Chlorophyll *a* analysis. The results clearly show nitrogen limitation of periphyton growth during that time, as well as significant additional periphyton growth in response to addition of P as well as N (Figure 1).

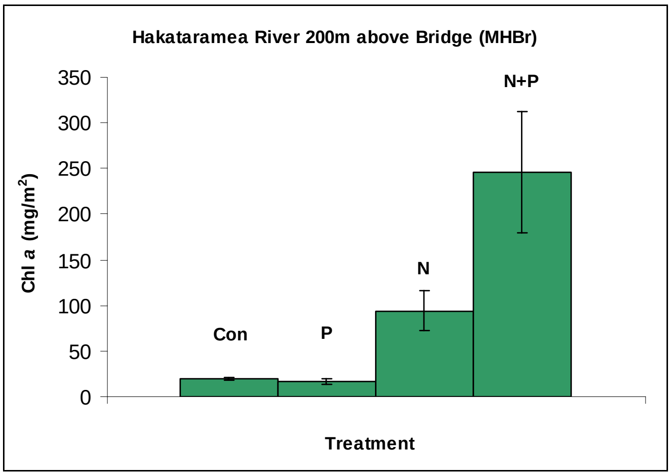


**Figure 1.** Periphyton responses to nutrient availability during a bioassay conducted near the Hakataramea MHBr site in March 2007. Data are expressed as chlorophyll *a* (+/- standard deviation) per square metre area.

From examining both DIN:DRP ratios and the *in situ* bioassay results, we consider that while nitrogen was the limiting nutrient during March 2007, nutrient ratios suggest that phosphorus is likely to often be the limiting nutrient. For the purpose of this study the biomass predictions based on phosphorus in Table 2 are more realistic. From a resource management perspective, the analysis demonstrates an important point, that no one nutrient is likely to consistently limit growth in the catchment all of the time. Therefore, any increase in either nitrogen or phosphorus could potentially cause growth effects, and mitigation measures (e.g., farm management measures) should aim to minimise any increase of both nitrogen and phosphorus. This is consistent with recommendations made recently by an expert New Zealand science panel assessing concerns for nutrient management generally (Wilcock et al. 2007).

## 2.7. Comparison of predicted nutrient concentrations with existing nutrient data

There is a moderate amount of river nutrient data available for the Hakataramea river catchment. In NIWA's national water quality database there is one site on the Hakataramea River at the main highway bridge (MHBr), and two sites in the Waitaki River, one at Kurow, and one at the State Highway 1 (SH1). These records consist of monthly water quality monitoring results which began in 1989. In addition to these data, there is also some nutrient data available from Environment Canterbury (ECan). There is data collected at the MHBr site between 1983 and 1985, however this data includes only one data point for dissolved reactive phosphorous. ECan has also gathered data from the Hakataramea River (at the Cattle Creek confluence) and several of its tributary streams since November 2004. Means and minimum - maximum ranges of these data are shown in Table 4.

Some of the data in Table 4 show extremely variable and high dissolved nutrient concentrations (e.g., Deadman Stream) that are probably caused by particular activities near those tributaries (e.g., deer grazing). The data illustrate the variable nature (variable both in space and in time) of some of the existing contaminant contributions to the Hakataramea River. For the purpose of making comparisons with predictions made in this report, we only use data from sites on the Hakataramea mainstem (i.e., Hakataramea @ MHBr; and the Hakataramea @ Cattle Creek – both in bold type in Table 4).

Calculated estimates for existing (scenario 1) DIN and DRP values (Table 1) are mostly higher than the actual measured concentrations (Table 4). The predicted DIN for Hakataramea at MHBr (586 $mg/m^3$) is about twice the highest measured concentration at that site (243 $mg/m^3$). Predicted DRP for the Hakataramea at MHBr (5.1 $mg/m^3$) is within the actual measured range but a little higher than the average measured concentration at that site (3.5 $mg/m^3$). In the upper Hakataramea at Wright's

Crossing, the predicted DIN (337 mg/m$^3$) is near the top of the range measured in the Hakataramea at Cattle Creek (8 – 388 mg/m$^3$). In contrast predicted DRP in the Hakataramea at Wright's Crossing (2.3 mg/m$^3$) is a little lower than the range measured in the Hakataramea at Cattle Creek (4 - 8 mg/m$^3$).

**Table 4:** Actual water quality data for dissolved inorganic nitrogen (DIN) and dissolved reactive phosphorus (DRP) for the Hakataramea and its tributaries. Sites used for making comparisons with predictions in this report are in bold type.

| Data source & Site | DIN (mg/m$^3$) | | | DRP (mg/m$^3$) | | | Number of samples |
|---|---|---|---|---|---|---|---|
| | Mean | Median | Min - Max | Mean | Median | Min - Max | |
| National database – TK4 Waitaki at Kurow (1989 - 05) | 17.9 | 15.5 | 0 - 49 | 0.8 | 0.7 | 0 - 5.8 | 194 |
| **National database – TK5 Hakataramea @ MHBr (89 - 05)** | **29.8** | **21.0** | **1.63 - 243** | **3.5** | **3.0** | **0.4 - 12.8** | **194** |
| National database – TK6 Waitaki at SH1 bridge (89 - 05) | 87.8 | 62.3 | 12.20 - 1113 | 3.5 | 1.1 | 0 - 60.3 | 194 |
| ECan – Hakataramea @ MHBR (1983 -85) | n/a | n/a | n/a | 7 | n/a | n/a | 1 |
| **ECan – Hakataramea @ Cattle Creek (Nov 04 – Jul 06)** | **95.6** | **27.0** | **8.5 - 388** | **5.4** | **5.0** | **4.0 - 8.0** | **5** |
| ECan – Cattle Creek (Nov 04 – Jul 06) | 108.2 | 16.0 | 11.0 - 811 | 4.3 | 4.5 | 1.0 - 8.0 | 10 |
| ECan – Rocky Point Stream (Nov 04 – Jul 06) | 127.6 | 25.5 | 5.0 - 821.0 | 18.1 | 17.0 | 3.0 - 35.0 | 10 |
| ECan – Deadman Stream (Nov 04 – Jul 06) | 1755.5 | 532.0 | 162.0 - 9743.0 | 29.8 | 20.5 | 10.0 - 120.0 | 10 |
| ECan – Kirkliston Stream (Nov 04 – Jul 06) | 59.1 | 19.8 | 9.5 - 346.0 | 18.4 | 20.5 | 6.0 - 26.0 | 10 |
| ECan – Padkins Stream (Nov 04 – Jul 06) | 86.8 | 40.0 | 14.5 - 479.0 | 4.1 | 3.0 | 0.5 - 11.0 | 9 |

From these comparisons between predicted and actual measured nutrient concentrations, the predicted DRP concentrations are closer to measured results than the predictions for DIN. This adds further support for predictions based on DRP, as adopted for estimating increases in algal biomass (Table 2). The differences between predicted and measured DIN and DRP concentrations are a reason for some caution to be applied when assessing consequences of the *absolute* predicted values. Several assumptions and potential biases in this assessment are summarised later in Section 3, with the conclusion that biomass predictions should best be considered as 'average' annual maximum biomass predictions – actual observed periphyton biomass can be expected to vary widely in both space and in time. Of importance for resource management decisions, the *relative differences* in predicted concentrations between scenarios is particularly useful for estimating relative effects of the different scenarios.

### 2.8. Comparison of predicted algal biomass with existing chlorophyll *a* data

There have been a few measurements of periphyton biomass in the Hakataramea River (Table 5) that can be used for making comparisons with predictions made in this report (Table 2).

Calculated estimates for existing (scenario 1) chlorophyll *a* (Table 2) are generally higher than the actual measured biomass data in Table 5, with predictions matching measurements better at the MHBr site than at Wright's Crossing. The predicted chlorophyll *a* for Hakataramea at MHBr (403 $mg/m^2$) is about twice the mean measured concentration at that site (185 $mg/m^2$) but within the measured range (23 – 408 $mg/m^2$). The predicted chlorophyll *a* for Hakataramea at Wright's Crossing (273 $mg/m^2$) is about 10 times the mean measured concentration at that site (24 $mg/m^2$). These comparisons should be treated with some caution as they are based on only three samples taken at each of the two sites on one day (Table 5).

For further comparison with the biomass predictions in Table 2, we know from historical observations that significant growths of periphyton do already occur in the Hakataramea River. One such bloom was photographed in February 1996 (Figure 2). We know that these blooms would take up significant amounts of dissolved nutrients from the water, as has been shown in studies on other rivers (e.g., Biggs and Close 1989). We note that the actual measured nutrient data (Table 4) represent nutrient concentrations after any biological uptake upstream. This could be one explanation for measured concentrations being generally lower than model predictions of the existing situation.

## 3. Discussion

*Comparison of biomass predictions between scenarios*

Predicted algal biomass is highest under scenario 3 (the irrigated community scheme) at both of the Hakataramea River sites (Table 2). Irrigation on a community scheme scale (scenario 3) could increase the average annual maximum biomass from 403 mg $m^{-2}$ to 662 mg $m^{-2}$, i.e., by more than one and a half times or about a 60% increase over the existing situation.

**Table 5:** Geometric mean periphtyon biomass data from stone surface samples from the Hakataramea River. Data are from two sources: Graham 1989; and samples taken during the 2006/07 summer specifically for the purpose of this study.

| Data source & Site | Chlorophyll a (mg/m$^2$) | | Ash-free dry mass (g/m$^2$) | | Number of samples |
|---|---|---|---|---|---|
| | Mean | Min - Max | Mean | Min - Max | |
| Hakataramea River Bridge (2 Feb 2007) -3 stone samples collected from riffle, run and river margin | 185 | 23 - 408 | 62 | 19 - 118 | 3 |
| Wright's Crossing (2 Feb 2007) -3 stone samples collected from riffle, run and river margin | 24 | 19 - 30 | 14 | 7 - 23 | 3 |

**Figure 2.** Photograph of periphtyon bloom taken from the Hakataramea Bridge in February 1996 Note: Unfortunately there is no chlorophyll *a* biomass measurement for this bloom – although clearly the bloom represents almost 100% cover of the riverbed with green filaments greater than 2cm in length, which exceeds all levels of the New Zealand periphyton guidelines (MfE 2000) (photo B. Biggs and C. Kilroy, NIWA).

If new water take consents were to be granted to all of those who have applied except the storage based community scheme (scenario 2), this could increase the average annual maximum biomass from 403 mg $m^{-2}$ to 481 mg $m^{-2}$, i.e., about a 20% increase over the existing situation.

If all existing irrigated land and all potentially irrigable land in the catchment was converted to dryland sheep production (scenario 4), this would reduce predicted average annual maximum biomass from the existing (scenario 1) 403 mg $m^{-2}$ to 188 mg $m^{-2}$, i.e., by about half.

*Comparsion of biomass predictions with guidelines*

The New Zealand Periphyton Guidelines (MfE 2000) use annual maximum and mean monthly algae biomass to define guideline thresholds for conditions that protect aesthetic, recreation and biodiversity values in rivers. The assessment in this report has estimated average annual maximum biomass for three future scenarios in the Hakataramea catchment (Table 2) and these can be compared with the Guidelines. The relevant maximum biomass criteria from the Guidelines to be considered here are:

1. For the protection of visual aesthetics, trout habitat and angling values, the Guidelines suggest a maximum chlorophyll *a* concentration of 120 mg $m^{-2}$ for filamentous periphyton, or 200 mg $m^{-2}$ if the periphyton community is dominated by diatoms.

2. For the protection of benthic biodiversity values, the Guidelines suggest the maximum chlorophyll *a* concentration of 50 mg $m^{-2}$, regardless of whether the periphyton community is dominated by filamentous algae or diatom films.

Considering the existing situation (scenario 1) first, results indicate that although predicted biomass is lower than the future irrigated scenarios, it still exceeded the (highest) 200 mg $m^{-2}$ criteria (Figure 3). In other words the assessment indicates that the Hakataramea River currently does not meet any of the maximum periphyton biomass guidelines. There is very little sampling data available to corroborate this prediction. However the prediction is not surprising to us because it is consistent with some past observations of conditions in this river. Results from our sampling in February 2007 (Table 5) exceeded the 120 mg $m^{-2}$ guideline and came close to the 200 mg $m^{-2}$ guideline at the MHBr Bridge, despite the fact that a significant fresh (78 $m^3$/s) occurred a month earlier (30 December 2006). Observations by NIWA staff during February 1996 showed that guidelines were almost certainly exceeded during that summer, although no samples were taken for chlorophyll *a* analysis (Figure 2). Again there had been a significant fresh (62 $m^3$/s) about a month prior to the photograph being taken, and so it appears that this bloom cannot be explained by an unusually low flow period.

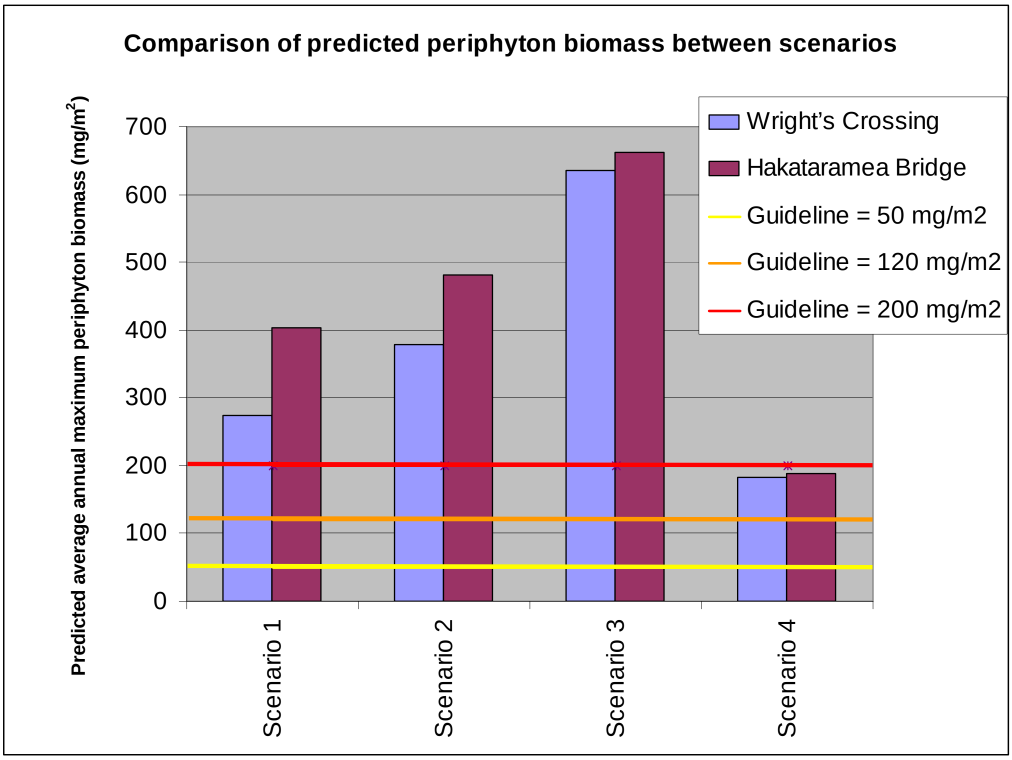


**Figure 3.** Predicted periphyton biomass for two sites in the Hakataramea River (Wright's Crossing and Hakataramea Bridge). The plot shows comparisons between scenarios and against New Zealand Periphyton Guideline (MfE 2000) criteria.

Considering the future irrigation scenarios, biomass predictions (Table 2) indicate that the (highest) 200 mg $m^{-2}$ guideline would, on average, be exceeded for both scenarios 2 and 3 (Figure 3). Irrigation on a community scheme scale (scenario 3) could exceed the 200 mg $m^{-2}$ guideline by about 330% at the Hakataramea Bridge site, while scenario 2 (if current water take consent applications were granted) could exceed the 200 mg $m^{-2}$ guideline by about 240% - compare both of these to the existing situation (scenario 1) which could exceed the guideline by about 200% (Figure 3).

Predictions for scenario 4 (where all irrigable land in the catchment is converted to dryland sheep production) suggest some improvement with biomass less than the 200 mg $m^{-2}$ guideline, but still exceeding the 50 and 120 mg $m^{-2}$ guidelines.

*Assumptions and biases*

The predictions in this report have been based (necessarily) on a number of assumptions. Some of these assumptions have the potential to bias the predictions towards over-estimates of periphyton biomass while some have the potential to under-estimate biomass. Three key assumptions are particularly relevant.

First, it has been assumed that the annual flux of nutrients is evenly distributed throughout the year - mean annual flows and mean annual nutrient loads have been used to calculate an estimate of mean nutrient concentration. This is likely to result in under-estimates of periphyton biomass, because in reality nutrient concentrations are likely to be higher than the annual mean during spring and summer because this is when irrigation occurs. In addition, spring and summer generally coincide with low river flows, warm temperatures and long sunlight hours, all of which support algae proliferation. Therefore the assessment is likely to have underestimated the potential maximum algae biomass, based on the nutrient concentrations used, particularly for locations where conditions are favourable, such as immediately downstream from irrigation runoff.

Second, the assessment used an average FRE3 condition for determining the accrual period for algal growth. The FRE3 statistic is based on a median statistic and so 50% of the time accrual periods will be longer than used in the predictions, with greater potential for biomass maxima, particularly at times of drought, high irrigation requirement, and lower than average river flow.

Third, the New Zealand Periphyton Guidelines (MfE 2000) are, also in general, conservative towards protecting instream values. This is because they suggest nutrient concentrations to prevent periphyton growth exceeding the suggested maximum biomass levels under an assumed set of other favourable conditions (i.e, no riparian shading and no grazing by invertebrates). In parts of the river where there is significant riparian vegetation shading the river channel and/or there is significant grazing activity by river invertebrates, it is possible that periphyton biomass would not proliferate to the extent predicted based on nutrient concentrations and flood frequency.

These confounding sets of assumptions illustrate that the results of the modelled scenarios are best considered as ‘average’ annual maximum biomass predictions - under different climate and physical habitat conditions the actual periphyton biomass observed can be expected to vary widely in both space and in time, being at times much worse (e.g., Figure 2) and at times better than predictions. We consider these to be best estimates based on available data and methodology.

*Best practice land management*

While it is beyond the scope of this report to consider nutrient reduction options in detail, we thought that we could usefully make some comments. We note that there is a suite of best land management practice options (often referred to as BMPs) including things like:

- efficient water and fertiliser application controls (nutrient budgeting),
- maintaining soil P levels at the optimum Olsen P level,
- feedpad wintering systems for controlling N losses,
- using nitrification inhibitors to manage N losses,
- managed stocking rates and soil maintenance for sustainable soil structure,
- management of stock access and effluent control in areas contributing directly to surface waterways,
- use of vegetation buffers between farm surface run-off and streams,
- riparian planting of stream margins.

The Clean Streams Accord, adopted by Fonterra, requires a series of actions including the fencing of waterways from stock and effective management of nutrients. Performance targets for the Accord are to have dairy cattle excluded from 50% of waterways by 2007 and 90% by 2012, with 100% of dairy farms having nutrient management systems by the end of 2007.

The potential effectiveness of best land management practices (BMPs) and other nutrient mitigation measures is a topic of much interest nationally. The agriculture and horticulture industries, regional authorities, central government agencies and research organisations are all working to achieve sustainable management of land and water resources during this time of high demand for development of these resources. Examples of effective BMP measures can be found in the literature, and a number of studies currently underway are attempting to measure the water quality benefits of BMPs at the catchment scale in New Zealand (e.g., Wilcock et al., 2006; Di et al., 1998; McDowell et al., 2004; Williamson et al., 1996). Effectiveness of these measures varies widely with quality of design and care in implementation, and will also be strongly influenced by nutrient loading rates and local conditions such as soils, climate, time-scale, and topography.

It is not yet possible to quantify the extent to which BMPs and other measures could reduce the effects of intensified land use in the Hakataramea catchment. However it is clear that a number of methods are potentially effective, and the more measures that are employed the greater the likely additive success. BMPs and other measures are unlikely to offset nutrient increases from intensive land use by 100%, but some reductions could be achieved. Nutrient contributions from existing land uses could be reduced as well as proposed new intensified land use. The goal of 50% reduction of contaminant loads adopted by the New Zealand dairy industry (Dairy Environment Review Group 2006) may be realistic, although ambitious and likely to require commitment over many years to achieve.

*Implications of Didymosphenia geminata (didymo)*

The recent arrival of *Didymosphenia geminata* (didymo) in the Waitaki catchment raises several further issues for this assessment. First, the relationship between nutrient concentrations, flood frequency and periphyton biomass used in this assessment were based on a model developed from data from many New Zealand rivers, before the establishment of didymo in this country. From our observations of didymo in New Zealand to date it seems likely that didymo will become established in the Hakataramea and, if this occurs, would grow to biomass levels that exceed all the periphyton guideline (MfE 2000) thresholds under all scenarios considered in this report. Didymo can maintain high biomass levels under low nutrient conditions, although we believe it is likely to grow more rapidly as nutrient availability increases.

# 4. Conclusion

The assessment indicates that the Hakataramea River currently does not meet any of the New Zealand Periphyton Guideline maximum biomass criteria for protecting visual aesthetic, benthic biodiversity, trout habitat and angling values. Periphyton biomass predictions for the existing situation exceeded the highest guideline criteria by about double. Predictions indicate that if new water take consents were granted to all of those who have applied, except for the storage based community scheme (scenario 2), this could increase algal biomass in the Hakataramea River by about 20% over the existing situation. Irrigation on a community scheme scale (scenario 3) could increase algal biomass by about 60% over the existing situation. If all existing irrigated land and all potentially irrigable land in the catchment was converted to dryland sheep production (scenario 4), this could reduce algal biomass by about half from the existing situation.

The predictions in this report have been based on a number of assumptions, some of which may bias the predictions towards over-estimates of periphyton biomass while some may under-estimate biomass. Overall, the predictions are best considered as 'average' annual maximum biomass predictions - under different climate and physical habitat conditions the actual periphyton biomass observed can be expected to vary widely in both space and in time, being at times worse and at times better. The biomass predictions for the existing situation have been corroborated to some extent by a few actual biomass measurements, and observations of periphyton blooms in the catchment in recent years. We consider these to be best estimates based on available data and methodology.

We conclude that:

- Periphyton blooms that breach the New Zealand Periphyton Guidelines occur periodically in the Hakataramea River under the current land-use conditions. Existing water abstraction is a contributor to this situation, due to water use for irrigation leading to more intensive land use and lower flows in the river.

- Future land use intensification is likely to cause further breaches in the New Zealand Periphyton Guidelines, by increasing the nutrient loading and increasing water takes, leading to further changes in algae biomass and trophic state in the Hakataramea River. This could decrease the value of the River in terms of aesthetic, aquatic ecology, trout habitat and angling values.

- Whether these changes are acceptable is outside the scope of this report and will depend on the objectives for management in this catchment. The Proposed Natural Resources Regional Plan (PNRRP) has set water quality outcomes for this catchment.

- There are a suite of best land management practices (BMPs) that can potentially reduce nutrient losses from land to groundwater and rivers. Some examples are listed in this report. The effectiveness of these methods varies widely with quality of design and care in implementation, and will also be strongly influenced by nutrient loading rates and local conditions such as soils, climate, time-scale, and topography.

- We also note that didymo is not currently present in the Hakataramea catchment, but if didymo did become established it would probably grow to biomass levels that exceed the New Zealand Periphyton Guideline thresholds under all scenarios.

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