Proposed dissolved reactive phosphorus guidelines for the Ruamahanga River

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Executive Summary

The Regional Freshwater Plan for the Wellington Region (RFPWR) identifies the Ruamahanga River as having regionally important amenity and recreation values. The RFPWR also identifies the need to enhance water quality in the mid and lower Ruamahanga, specifically for the purpose of contact recreation. Community wastewater discharges like the Masterton pond discharge can affect contact recreation values in a number of ways, one of which is by increasing nutrient concentrations that can, under the right circumstances, lead to nuisance growths of algae in rivers. Such growths do occur at times in the Ruamahanga River. One possible method for managing these is to determine whether an appropriate nutrient concentration guideline, for either dissolved reactive phosphorus (DRP) or dissolved inorganic nitrogen (DIN), can be achieved such that nuisance growths will be minimised.

This report reviews both the RFPWR and the Manawatu Catchment Water Quality Plan (MCWQP) to assess whether the methodology for setting the in-river nutrient (in this case DRP) standard in the latter Plan, is appropriate for the Ruamahanga River. The Ruamahanga River flow regime was critically examined to determine the appropriate accrual period[1] for use with national nutrient guidelines, the *NZ Periphyton Guidelines* (MfE 2000). A mathematical model was applied to predict benthic algal growths in relation to river flood events and predict algal biomass in reaches upstream and downstream of the Masterton wastewater discharge for the summer periods for 1988 to 2002.

The RFPWR indicates that nuisance growths must be considered and the guidelines provide some guidance relative to potential nutrient thresholds – however, these do not constitute a requirement to meet these guideline values. The scientific analysis has shown that high nutrient levels are naturally present upstream and that the Ruamahanga River is generally dominated by a high frequency of significant flood events during summer periods. The modelling predictions have indicated that nuisance growths will occur, but will generally be of short duration; occurring in 6 of the 15 years, with durations from 3.5d to 35d, with most being of around 5d. The frequency and duration of predicted nuisance growths would be considered low, generally occurring for only a minimum fraction of the summer season. Furthermore, the algal growth model suggests that differences in river-bed slope are the major factor affecting algal abundance in the Ruamahanga River, rather than increased nutrient concentrations. Consideration of the mass loads indicates that the Masterton discharge is a significant phosphorus load to the river, but still markedly less than cumulative non-point loads.

The use of the *NZ Periphyton Guidelines* (MfE 2000) requires an understanding of the 'mean days of accrual' which is not defined in that document. We provide a detailed analysis of the flow variability for the Manawatu and Ruamahanga rivers. We recommend that the accrual period calculation for application of the guidelines to the Ruamahanga River be based on: (i) summer median flow and flood

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[1] Accrual period is the time required for peak algal growths to occur

frequency (FRE3[2]); (ii) daily mean flow data and (iii) 1-day duration ('filter period'[3]) between significant floods. Based on the above assumptions the FRE3 for Ruamahanga was 13 floods/summer, giving an accrual period of 13 days in summer (Manawatu: FRE3, 8 floods/summer, accrual period 21 days). Using this data to apply the guidelines gives a DRP criteria of 30 mg/m^3, that is predicted by the guidelines, based on an empirical model, to achieve the biomass objective of 120 mg/m^2 chlorophyll *a*[4]. However, it should be noted that there is a high degree of uncertainty in the data used to derive the biomass/accrual period relationship as used and acknowledged in the MfE (2000) guidelines.

Thus, while nutrient targets may be established for the Ruamahanga River and subsequently calculated for the wastewater discharge, the improvements in river condition in terms of reduction in average nuisance algal biofilm growths will be slight – since flood frequency and high upstream phosphorus concentration are controlling growths for the majority of the time. Phosphorus limitation will only occur under maximum algal growths conditions, which occur during long periods of low flow. Improving river water quality by reduction in phosphorus load is desirable in the context of a component of overall phosphorus reduction measures (point and non-point sources). Thus the key consideration in relation to implementation of the wastewater treatment plant upgrade relates to cost-effective implementation of phosphorus reduction systems.

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[2] FRE3 is a flow statistic calculated as the frequency of floods exceeding 3 times the median flow.

[3] 'Filter period' used here is a calculation factor that is the chosen number of days between flood peaks at which the 'flood' is assumed to be a single event.

[4] Chlorophyll *a* is a pigment present in algae that can be measured and the result used as an indicator of algae biomass per given area of sample. The guidelines (MfE 2000) suggest that a maximum chlorophyll *a* result of 120 mg/m^2 (taken as the average of samples across a transect) is an appropriate biomass objective for rivers being managed for recreation and aesthetic values (MfE 2000 – Executive Summary Table 1).

1. Introduction

This report extends the review of water quality in the Ruamahanga River and the summer 2003 studies undertaken to measure attached periphyton growth in the river upstream and downstream of the Masterton wastewater discharge (Hickey 2004).

The scope of work required by Beca was outlined as follows:

1. Review the Manawatu Catchment Water Quality Plan (MCWQP) to assess whether the methodology used for setting the in-river dissolved reactive phosphorus (DRP) level for the Manawatu River is appropriate for the Ruamahanga River.
2. Review the appropriateness of less than half median flows as a trigger point for the DRP guideline to apply.
3. Review the appropriateness of 2 percentile low flows as a minimum to avoid environmental effects.
4. Determine an appropriate DRP receiving water guideline for the Ruamahanga River and the flow regime at which this should apply.
5. Refine the algae growth model (previously using the 2002/03 summer data) using all the historical data.

Items 1 to 4 review the Ruamahanga River nutrient issues in relation to the MCWQP, since this provides the major example in New Zealand where nutrient standards have been established as rules in a regional plan, and nutrient stripping measures have been implemented to meet the required plan standards. Comparisons with the Manawatu case are made within the context of the statutory relevant plan for the Ruamahanga River, which is the Regional Freshwater Plan for the Wellington Region (RFPWR). The review also critically considers other precedents for establishing low flow thresholds for compliance with plan standards, and the practicalities of operational criteria for phosphorus removal processes. A key component of this review was that the New Zealand Ministry for the Environment "New Zealand periphyton guideline: detecting, monitoring and managing enrichment of streams" (MfE 2000) has been released since the Manawatu MCWQP standards were adopted.

The river modelling of attached benthic periphyton was undertaken by Dr Niall Broekhuizen, who has developed and successfully applied a periphyton growth model for small streams in the Whatawhata catchment near Hamilton. This model incorporates algal biofilm growth, grazing and loss through flooding. The model has been parameterised and run for several upstream and downstream reaches in the Ruamahanga River and calibrated based on the monitoring year (2003). The model was then run for the years where the hydrological record has been summarised (1988-2002). We undertake no guarantee about the success of this as a predictive tool because it has not previously been applied to systems which are either (a) perennially nutrient rich or (b) large rivers. However, we are moderately confident that the flood disturbance and relative upstream/downstream growths will be simulated. The key reason for undertaking this modelling is to provide simulations of the flood-dominated behaviour of the attached algal growths and investigate the role of DRP in the Ruamahanga River.

2. Proposing an appropriate DRP receiving water criteria

2.1. Introduction

The first thing to recognise when proposing a DRP receiving water criteria for the Ruamahanga River, is that there is no strictly right or wrong number. The Resource Management Act (RMA) and the relevant statutory plan for the Ruamahanga River, the Regional Freshwater Plan for the Wellington Region (RFPWR), both place narrative restrictions on granting permits for discharges to water, but neither document contains any regulation or numeric standard for DRP. Both documents rely on case-by-case, effects-based assessment of wastewater discharge permit applications.

The key steps were:

- Identify values, issues and objectives for the Ruamahanga River by reviewing the Regional Freshwater Plan for the Wellington Region (RFPWR).

- Review national guidelines and other regional plans (in particular the Manawatu Catchment Water Quality Plan) and similar discharge cases that may provide useful precedents for comparison.

- Use the New Zealand Periphyton Guideline (MfE 2000), in combination with the findings of a study that specifically investigated the role of nutrients in promoting algal growths downstream of the Masterton discharge (Hickey 2004), as well as hydrological information for the Ruamahanga River, to propose a periphyton biomass objective, an associated DRP receiving water criteria, and the flow regime at which the DRP criteria should apply.

2.2. Review of the Regional Freshwater Plan for Wellington Region (RFPWR)

The key parts of the RFPWR that are relevant for considering an application for consent to discharge nutrients to the Ruamahanga River are summarised in the flow diagram in Appendix 1. The RFPWR covers the whole of the Wellington region and is fairly general in its content regarding discharges to a specific river such as the Ruamahanga. The key points are:

- The Ruamahanga River is identified as having regionally important amenity and recreation values, in particular canoeing, kayaking and angling, for the reach downstream of Masterton (Figure 5, RFPWR).

- The mid and lower Ruamahanga River is identified as having water quality that needs enhancement, specifically for the purpose of contact recreation (Policy 5.2.9 and Figure 7, RFPWR).

- It is recognised that there will be some existing discharges that may have effects that are in conflict with the policies to enhance water quality in the Ruamahanga River for contact recreation. Allowance is made for permits for such discharges to be considered in terms of an appropriate cost and timeframe to enhance water quality (Policy 5.2.10) and to encourage users to consider discharge to land as an alternative where possible (Policy 5.2.12).

- Under the RFPWR rules (Rule 5) the Masterton wastewater discharge is a *discretionary activity*. The RFPWR contains no other rules that specifically prescribe any measure of environmental quality for the discharge. Some guidance is provided for preparing consent applications, by way of direction to appropriate national water quality guidelines (Appendix 8, RFPWR).

2.3. Review of the Manawatu Catchment Water Quality Plan (MCWQP)

The brief from Beca was to review the MCWQP in order to assess whether the methodology for setting the in-river dissolved reactive phosphorus (DRP) is appropriate for the Ruamahanga River, and to also specifically assess the appropriateness of the half median flow and 2 percentile low flows as the flow band within which the DRP guideline should apply.

The general methodology used in the MCWQP probably represents one of the best examples of a regional plan nationally which establishes a clear linkage between objectives, policies, methods (including rule standards) and the reasons for adopting these methods. It is one of the few regional plans to have set a numeric standard for DRP. In this respect the general approach of the MCWQP is a useful one to consider.

Both the Manawatu and Ruamahanga Rivers receive community wastewater discharges and both have been identified in their respective regional plans as needing to be managed for the key value of contact recreation (Policy 1 in MCWQP; Policy

5.2.9 in RFPWR). In this respect, we are dealing with the same general management purpose for both rivers.

For both rivers, DRP has been identified as the limiting nutrient for algae (periphyton) growths that can adversely affect recreation values (including amenity and aesthetic values). The MCWQP sets a numeric standard for periphyton biomass (measured as mg/m^2 chlorophyll *a*) that is deemed to maintain recreation values at a level of protection that was accepted by the Manawatu-Wanganui Regional Council when the plan became operative on 6 October 1998. The MCWQP also sets a DRP concentration standard that is predicted to ensure that this biomass standard is achieved. The DRP standard is written in such a way that compliance is only necessary where other physical or biological factors are not limiting nuisance growths (e.g., riparian shading, substrate instability, or invertebrate grazing). The MCWQP also defines the Manawatu River flows within which it is necessary to comply with these standards.

While the MCWQP is a useful example to consider, it is important to recognise that it has no statutory meaning for the Ruamahanga River. Any numeric standards for periphyton biomass and/or DRP should be set specifically for the Ruamahanga River situation, rather than simply adopting the Manawatu standards. There are two key factors contributing to this:

1. First, the MCWQP standard for maximum periphyton cover (40%), the associated maximum biomass standard (100 mg/m^2 chlorophyll *a*) and the associated DRP standard predicted to achieve this biomass (15 mg/m^3) were derived (see page 50 MCWQP) from the *Guidelines for the Control of Undesirable Biological Growths* (MfE 1992) which have since been superseded by the *NZ Periphyton Guidelines* (Biggs 2000). The revised numbers that correspond to the same purpose for management (contact recreation including aesthetics) are less than 30 % cover of filaments greater than 2cm long, less than 60% cover for films greater than 0.3cm thick, an associated biomass objective of 120 mg/m^2 chlorophyll *a*, and an associated DRP criteria to achieve this biomass that is described by a function of accrual period (flood frequency) that is river-specific.

2. Second, there is a need to consider the physical differences between the two rivers and how this influences the likelihood of nuisance growths and therefore appropriate periphyton and nutrient criteria. Most importantly, the river flow hydrograph needs to be considered to define the accrual period for

setting DRP criteria from the new guidelines. It is also necessary to consider whether other conditions are favourable for nuisance growths and therefore whether a nutrient limit is necessary at all (Note: This has been done - see Executive Summary page iv, Hickey 2003).

2.3.1. MCWQP rationale for the 'half median flow statistic' as a trigger point for the DRP guideline to apply

This trigger point is set for the Manawatu water quality standards in Policy 1a of the MCWQP. The rationale is simply that the purpose for management is 'contact recreation' and it is presented in the MCWQP that contact recreation occurs most commonly in the Manawatu River during approximately the lowest 20-25 percentile of river flows. On the Manawatu hydrograph this corresponds approximately to half the median flow and thus the simple statistic has been adopted. It is not clear from the MCWQP whether this is based on any recreation surveys. It is simply noted that these bottom 20-25 percentile flows occur most commonly between 1 November and 1 May, which is when recreation is most common (see pages 15 and 41 MCWQP). The Manawatu-Wanganui Regional Council was satisfied that this approach was reasonable for the Manawatu River when the plan became operative on 6 October 1998.

It would not be appropriate to blindly adopt the half median statistic for other rivers because this statistic varies depending on the shape of the hydrograph, which is river-specific. However the hydrograph for the Ruamahanga River (@Wardells) is a similar shape to the hydrograph for the Manawatu River, and in this respect half the median flow does correspond to approximately the 20 percentile flow for the Ruamahanga River. Therefore, if the assumption that river recreational use is most common during the bottom 20 percentile of flows can be accepted, then the half median flow statistic is a reasonable trigger point to borrow, and propose, for the Ruamahanga River.

2.3.2. MCWQP rationale for the '2 percentile low flow statistic' as a minimum point for the DRP guideline to apply

This minimum flow has been set for the Manawatu water quality standards in Policy 2 of the MCWQP. This policy stems from the fact that the RMA requires that Councils may not grant discharge permits that have certain effects (e.g., s107 RMA), and in the case of the MCWQP, may not breach the rule-defined water quality standards, except for a number of circumstances. These circumstances include "exceptional" and "temporary" circumstances. The Manawatu-Wanganui Regional Council went through a rational process to satisfy itself that the bottom 2 percent of flows in the Manawatu Catchment "…*could be regarded as exceptional circumstances and that they were of a temporary nature, and further, that providing for this situation was necessary to achieve the purpose of the Act because the level to which the standards would be exceeded would not be sufficient to endanger the life-supporting capacity of the river and would only result in a temporary decrease in the aesthetic value of the river*" (see page 41, MCWQP).

This effectively amounts to finding that a breach of the standards on seven days out of the bottom 20 percentile flow days out of every year is a reasonable and acceptable situation for the standards in question. A similar assumption seems reasonable, and is probably defensible on the basis of the Manawatu precedent, for the Ruamahanga River. Note that none of the standards in question are for acutely toxic contaminants and so it can be reasoned that a seven day per year breach will not be sufficient to "endanger the life-supporting capacity of the river". This reasoning would be less robust for standards for highly toxic contaminants.

Because this definition has no statutory meaning for the Ruamahanga River, and the RFPWR does not define the narrative terms "exceptional" and "temporary", there is nothing to prevent a consent applicant from proposing a more enabling definition (e.g., 5 percentile low flows). This would amount to approximately 18 days out of the lowest 20 percent of flow days each year. Such a proposal would need to be supported by a quantification of the difference in predicted effects (i.e., predicted frequency and duration of blooms upstream and downstream of the discharge) in order that the consent decision makers could be comfortable moving beyond the Manawatu precedent.

2.4. Proposed DRP receiving water guideline for the Ruamahanga River

The brief from Beca was to determine an appropriate DRP receiving water guideline for the Ruamahanga River and the flow regime at which this should apply.

We have followed the process illustrated in Appendix 1 to propose a DRP receiving water criteria for the Masterton wastewater discharge to the Ruamahanga River.

The key points are:

1. Establish the management purpose that Greater Wellington has defined for the Ruamahanga River. à 'contact recreation'.

2. Use the *NZ Periphyton Guidelines* (MfE 2000) to propose a periphyton biomass objective that meets this management purpose at a level of protection proposed by the national guideline. à **<u>120 mg/m^2 chlorophyll *a*</u>** (and/or associated percentage cover objectives).

3. Establish which nutrient is limiting nuisance growths and check that other factors (e.g., riparian shading or invertebrate grazing) are not significantly limiting nuisance growths. Thereby establish whether a nutrient criteria is an appropriate management method. à DRP is the limiting nutrient for algal biomass and invertebrate grazing was a significant factor only at some times during summer (Hickey 2004).

4. Use of the *NZ Periphyton Guidelines* (MfE 2000) requires an understanding of the ‘mean days of accrual’ which is not defined in that document, but is referenced to various publications by Biggs on this matter. The data shown in Figure 2.1 is the basis for the guidelines derivation – we have superimposed the Ruamahanga sampling data for 2003 (note the large range of uncertainty for rivers with comparable accrual periods). We have examined these publications and undertaken flow analyses for both the Manawatu and Ruamahanga rivers (see Appendix 2). These flow analyses calculated the frequency of floods exceeding 3 times the median flow (a statistic known as FRE3) on an annual and summer basis (defined as 1 November – 30 April), compared the use of instantaneous or daily flows, and tested the sensitivity of the calculation to different flood interval ‘filter periods’[5]. The data illustrates that both the Manawatu and Ruamahanga rivers have relatively high flood frequencies that differ markedly with the different factors. We have chosen a combination of these factors on the following basis:

    a. *Annual versus summer flow data?* - We note that the publications deriving the nutrient guidelines (including Clausen & Biggs 1997; Biggs 2000) use annual median flow and daily mean data for flood frequency calculation in deriving the published relationships (M. Duncan, pers. comm.). However, we consider that for the Ruamahanga case, application should be based on considering the summer period, as the nutrient guidelines note that this is the period of interest for effects on recreation and aesthetics (Note: In many rivers summer will also be the defining

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[5] The ‘filter period’ is the chosen number of days between flood peaks at which the ‘flood’ is assumed to be a single event. This period is required to allow the algae to begin significant growth following a flood event. Our analysis considered filter periods of 1 to 7 days (see Appendix Table A2.2.

period for flood frequency analysis – however inspection of both the Manawatu and Ruamahanga river data shows only small differences between the days of accrual calculated from summer or annual data (see Appendix Table A2.2)).

b. *Instantaneous versus daily mean flow data?* – The sensitivity of algal growths to being sheared from the riverbed is dependent on instantaneous flow (i.e., strong peak flow dependence). While instantaneous flow data is used in the following modelling section 3, we consider that the daily mean flow provides a more pragmatic measure for ease of calculation of FRE3 statistics.

c. *Flood interval filter period?* - The time interval or 'filter period'[4] between counting significant floods has a marked effect (e.g., for Ruamahanga median summer daily average flow FRE3: 1-day between floods = 13 floods/summer; 5-day between floods = 10 floods/summer; Appendix Table A2.2). We consider that a 1-day period is appropriate in this case, based on maximum algal growth rate measured in the Ruamahanga River, which could have significant growth over a 5-day period (maximum linear rate 7 mg Chl *a*/d, Table 5.3, Hickey, 2003).

In summary, for calculating the accrual period to use in applying the guidelines to the Ruamahanga case, we recommend the following: (i) summer median flow and flood frequency (FRE3); (ii) daily mean flow data and (iii) 1-day duration (filter period) between significant floods.

5. Based on the above assumptions the FRE3 for Ruamahanga was 13 floods/summer, giving an accrual period of 13 d in summer (Manawatu: FRE3, 8 floods/summer, accrual 21d). Using this data gives a DRP criteria of **30 mg/m^3**, that is predicted in the guidelines, based on an empirical model, to achieve the biomass objective of 120 mg/m^2 chlorophyll *a* (Table 2.1). Note that the Manawatu River case would give a DRP criteria of approximately 3-4 mg/m^3 using this empirical relationship – a value markedly lower than the 15 mg/m^3 currently adopted in the MCWQP. This tabulated data illustrates the extreme sensitivity of the peak biomass threshold to the days of accrual value. It should be noted that there is a high degree of uncertainty in the data used to derive the biomass/accrual time relationship (see Fig. 2.1) as used in the MfE (2000) guidelines.

6. It seems reasonable to propose that the DRP criteria should apply at Ruamahanga River flows that lie in the band between the 2 percentile low flow and the half median flow. However, in doing this it should be recognised that borrowing these statistics from the MCWQP assumes that most river recreation occurs during the bottom 20 percentile of river flows. Some further analysis could be undertaken to look at the periods of duration in relation to various low flow percentiles during summer periods. The theoretical basis for this analysis would be that once a duration period was exceeded (say 20d), then maximal algal blooms would be established and the presence of additional nutrients at that time would make negligible difference. However, the algal growth model for the Ruamahanga River (see following section) indicates that the nutrient results in only slight changes to algal biomass.

7. The above process is robust and, we judge, moderately conservative for the environment. However readers should recognise that the process for proposing the DRP criteria has, at several of the steps, borrowed value judgements from elsewhere about what is an appropriate level of protection for the management purpose (step 1 above) and what is an appropriate flow band for compliance (step 6 above). There is also a very high sensitivity to the accrual flow statistic calculation that is used in the nutrient growth regression relationship provided in the guidelines (see Table 2.1; 13-d accrual = 30 mg/m^3; 15-d = 15 mg/m^3; 20-d = ca. 3 mg/m^3). There is nothing in the statutory planning framework that prevents a consent applicant from proposing a DRP criteria and a set of compliance statistics that accepts risk of a higher frequency of nuisance growths. Alternatives would need to be considered, and a sound rationale developed, within the context of treatment engineering requirements, the social and economic costs of treatment to the community, and the scale of the increased risk of environmental effects. The national guidelines can be conservatively restrictive (see page 104, MfE 2000). The RFPWR specifically acknowledges the time and cost elements to achieve water quality improvements (Policies 5.2.10 and 5.2.13).

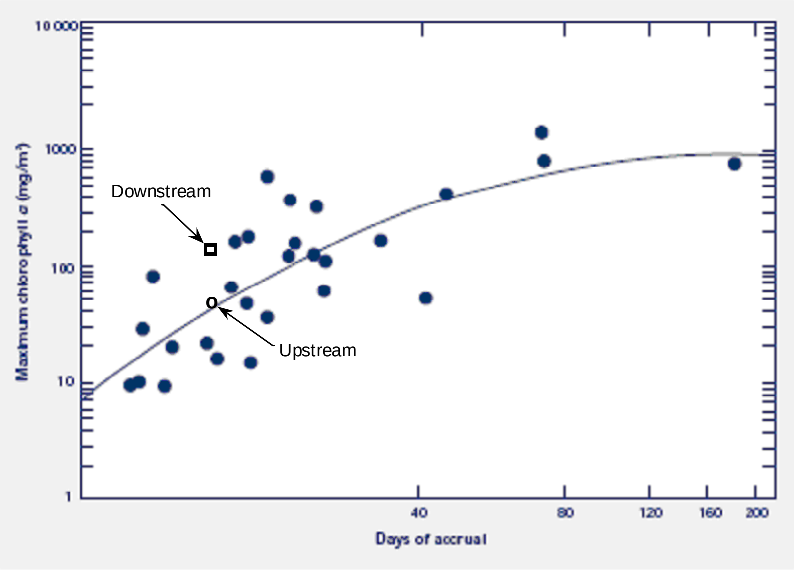


Figure 2.1: Relationship between maximum Chlorophyll *a* and accrual time for various New Zealand streams (from MfE 2000) with Ruamahunga data for March 2003 added (from Hickey 2003).

Table 2.1: Predicted algal biomass (as maximum chlorophyll *a*, mg/m^2) as a function of soluble reactive phosphorus (SRP, mg/m^3) and days of accrual (duration of stable flow) (calculated from MfE 2000, p43, eqn 2). Shaded results are for a 13d accrual period.

SRP conc (mg/m^3)	**Accrual time (d)**				
	10	**13**	**15**	**20**	**30**
2	16	32	47	94	222
5	25	51	73	147	349
10	35	71	103	207	492
15	42	87	126	253	601
20	49	101	146	292	693
25	55	112	163	326	774
30	60	123	178	356	847
40	69	142	205	411	976
50	77	158	229	459	1090

2.5. Nutrient mass loads to the Ruamahanga River

The following section is an analysis undertaken by Mr Graham Sevicke-Jones (formally Greater Wellington Regional Council, 15 August 2003).

Figures 2.2 and 2.3 show nitrogen and phosphorus loads on the Ruamahanga River and some of its tributaries. These loads originate from land use and major point source discharges and are summarised in Table 2.1. The loads have been calculated from state of the environment and compliance monitoring data and mean annual river flows. There are limited data available so these cannot be viewed as definitive but they show the relative contributions of non-point and point source nutrients within the Ruamahanga River system.

The graphs show the increasing amount of nitrogen and phosphorus carried by the river as it flows downstream. They also show that inputs from the Makoura Stream, the receiving water for the discharge from Masterton's Wastewater Treatment Plant (WTP), and the Papawai Stream, which receives Greytown's WTP, are only partly responsible for this increase. This means that reducing the total load will require a reduction in all inputs, not just direct discharges. Two nutrient sources likely to be affecting the overall load are inputs from stock with access to waterways and runoff from fertiliser applications that are not based on an on-farm nutrient budget.

Distances from the source of flow (head waters) are shown in brackets. The loads to the Ruamahanga River and to its tributaries vary by an order of magnitude so the minor inputs cannot be seen easily. Despite this, a logarithmic scale was not used because it can give an impression of similarity between sites. Using linear scales clearly shows the magnitude of difference as the river flows from the source through farmland to the sea.

Table 2.1: Summary of major point and non-point source loads to the Ruamahanga River (G. Sevicke-Jones, Greater Wellington Regional Council, unpublished data).

Site	Total Nitrogen (tonnes/yr)	Total Phosphorus (tonnes/yr)
Mt Bruce	28.9	2.6
Double Bridges	57.7	3.3
Te Ore Ore	314.2	15.6
Makoura Stream above STP	16.0	0.2
Masterton STP	58	12.5
Gladstone	675.4	45.4
Mangaterere Stream Above STP	109.0	2.8
Carterton STP	7.4	1.6
Papawai Stream above STP	20.6	0.4
Greytown STP	5	1.6
Waihenga	1792.1	121.3
Martinborough STP	3.6	1.8
Donalds Creek above STP	1.0	0.03
Featherston STP	3.2	1

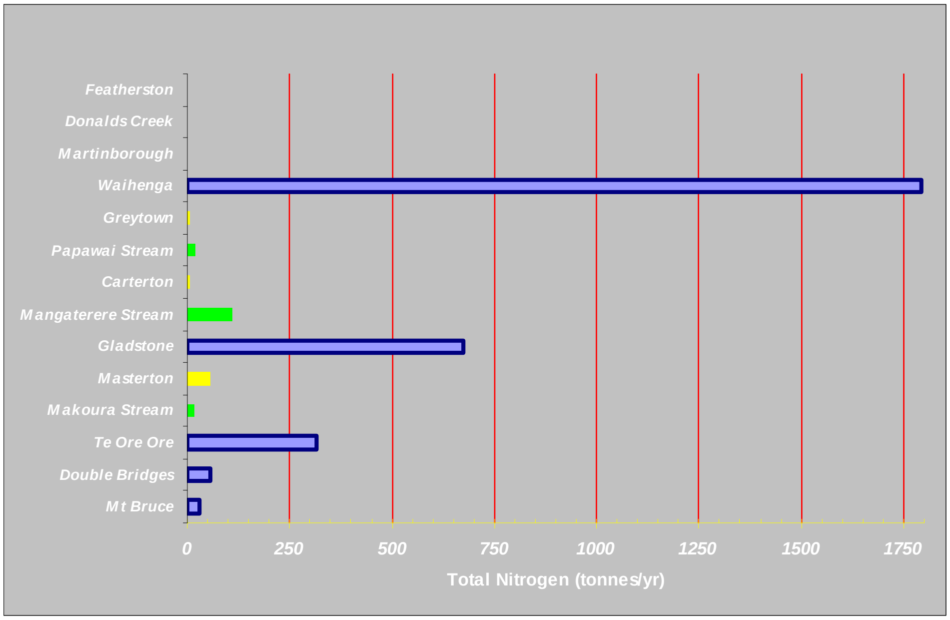


Figure 2.2: Total Nitrogen load to the Ruamahanga River, source to the sea.

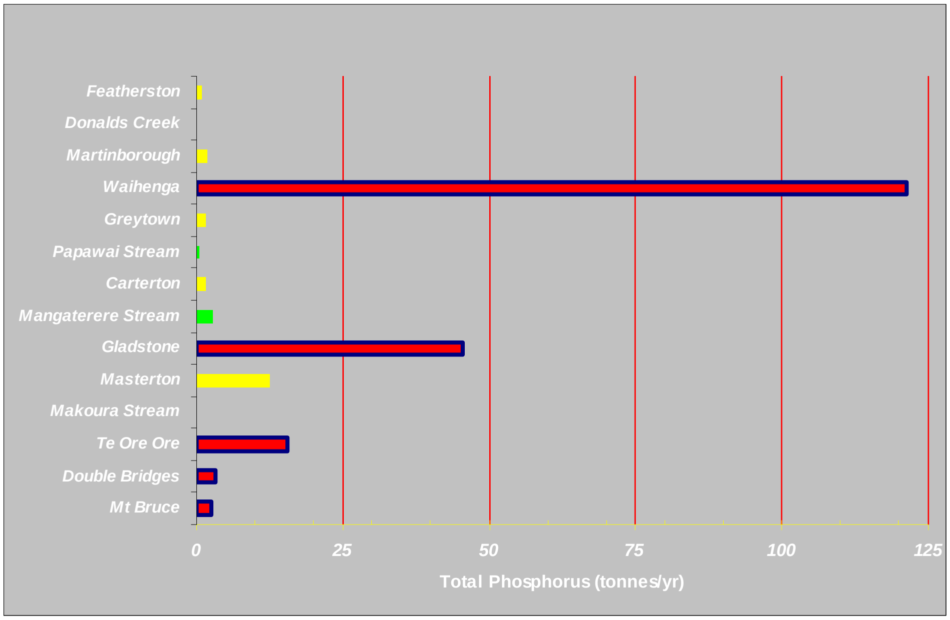


Figure 2.3: Total Phosphorus load to the Ruamahanga River, source to the sea.

Notes:

1. Results of Ruamahanga River nutrient loads (mean concentrations) derived from sampling period (monthly interval) from July 2001 - September 2002.

2. STP loads (mean concentrations) shown in red, and tributary loads (mean concentrations) shown in blue, were derived from consent data 1996-2001 (up to 50 data sets used).

3. Donalds Creek flows into Lake Wairarapa and although part of the Ruamahanga system its contribution is likely to be assimilated before the lake discharges to the lower Ruamahanga River system.

4. The receiving water streams or rivers (green bars) have their loads represented prior to the wastewater discharges. To calculate the actual contribution of the tributaries to the Ruamahanga River the point source load and tributary load would need to be added.

5. The Waihenga sampling site is the last site on the Ruamahanga River and is upstream of the confluence with Donalds Creek. There is no site downstream of all discharges.

3. Development of algae growth model to predict attached growths using all the historical data

3.1. Summary of the model

The simulation model that we used is described in Broekhuizen et al. (2004). In this application, we set the abundances of dissolved organic material, particulate organic detritus and invertebrates to zero, and considered only water, nutrients and periphyton. We subdivided the Ruamahanga into 9 serially connected sub-reaches (defined to coincide with the nine upstream survey cross-sections of “Masterton Oxidation Ponds Long-section for Gravel Extraction consent”). Reach number 2 includes the site ‘RUA1’ from the 2003 monitoring. Reach number 8 includes the site ‘RUA2’ and reach number 9 includes the site ‘RUA3’. Reach details are provided in Appendix 4. Notably, the average reach slopes varies markedly with the lowest slope being at Wardells Bridge (0.07%) and a 3X higher slope at the upstream RUA1 site (0.21%). These differences have marked effects on the shear stress experienced by attached algae during flood events.

We used the 1997/2002 monitoring data from Te Ore Ore to derive upstream boundary condition nutrient concentrations. Specifically, we calculated monthly average nutrient concentrations using these data. These were assumed to apply on the 15th day of each month, and we used linear interpolation to derive instantaneous values.

Upstream boundary condition flow time-series were derived from half-hourly measurements (1988-2003) at Wardells Bridge. Where there were missing data, we applied the last-measured-value until such time as recording recommenced. There was one especially long period where there were no data: December 18, 1990- Jan. 9, 1991.

We assumed that diffuse source inputs are negligible, and applied a point-source input of water and nutrient to reach 6 (corresponding to the reach into which the Makoura flows). For this reach, we adopted the monthly average flow and nutrient concentrations flowing out of the sewage Pond (Beca data).

The simulations were run from November 1st of each year until April 1st of the following year; however, in the subsequent bloom frequency analysis, we discarded all the November results in order to minimise any bias that would arise should our initial periphyton abundances have been inappropriate.

The differential equations comprising the model were solved using an adaptive fourth order Runge-Kutta scheme with a maximum time-step of 0.002 d.

3.2. Calibration to 02/03 monitoring data

The bulk of the model's parameters were left at their default values (Broekhuizen et al. 2004), however this model has previously been applied only to head-water streams. For this application we allowed ourselves the luxury of modifying the following parameter groups:

a) those governing the relationships between flow and water-depth, channel width and water velocity (power-law relationships were derived from channel-cross-section data and the RYHABSIM, I. Jowett, *pers. comm.*, Appendix 3).

b) the within-water-column light-extinction coefficient. We adopted a value of 1.3 m^{-1}, based upon empirical relationships relating the extinction coefficient to turbidity and yellow colour (with yellow colour derived from TOC via additional empirical relationships). We adopted the summertime median turbidity and TOC values measured at Te Ore Ore.

c) Formulation and parameterisation of the relationship between flow (bed-shear) and periphyton mortality. Broekhuizen et al. (2004) assumed the erosional mortality to be a continuous function of the bed-shear; however this description proved unsatisfactory when applied to the Ruamahanga. We believe this is because the flood events are much longer-lasting in this system. We therefore introduced an alternative formulation – in which flow-induced removal is zero for most of the time, but introduces discrete 'reset-events' when the product of reach-specific periphyton density and reach-specific bed-shear comes to exceed a (dynamic) threshold. The threshold in question is defined to be:

$$F_{thresh} = F + 40B\exp\left(-\frac{B}{1000}\right)$$

with *F* varying according to the ODE (Ordinary Differential Equation):

$$\frac{dF}{dt} = \alpha\left(B\max\left(\tau, \tau_{\max}\right) - F\right)$$

in which B is the local periphyton density (mg C m^{-2}), τ is the local bed-shear (N m^{-2}), $\tau_{\max}$ (=35 N m^{-2}) is the maximum bed-shear to which a mat can adapt, and α is a maximum adaptive rate, and ε (dimensionless) is a 'capacity to withstand additional shear'. We emphasize that this description is pure hypothetical. It was adopted as having appropriate characteristics: (a) periphyton have some ability to adapt to (slowly changing) flow, (b) catastrophic loss becomes more likely as flow (bed shear) and periphyton biomass rise.

When the product of instantaneous reach-specific bed-shear and reach specific periphyton come to exceed F_{thresh}, a fraction (ϕ) of the periphyton is removed (note, however that *the 'shear-state'* of the periphyton (*F*) is not modified and tends to remain 'high' for some time following the mat's failure (delaying the onset of further failures, should flow remain persistently high):

$$\phi = 0.9\frac{B}{1250 + B}$$

The numeric (*cf* symbolic) coefficients in the aforementioned equations (namely 40, 1000, 0.9 and 1250) were selected by visual calibration of the model to the data gathered during the 2002/2003 season (Fig 3.1).

The calibrated model reproduces the periphytic biomasses during the mid-season relatively well, but it fails to reproduce the very rapid growth that occurred between early and mid-March (Fig. 3.1). One might surmise that this is a result of driving the model using long-term, monthly average Te Ore Ore nutrient concentrations as our upstream boundary condition rather than those measured at site RUA 1 during the 2003 monitoring period; however, we have also run the model using the nutrient concentrations measured during NIWA's 2003 study. This did not improve the model's performance. Flood events did induce marked reductions in periphytic biomass, with the extent of reset being dependent on the relationship between the size of the flood event and the bed slope in that reach.

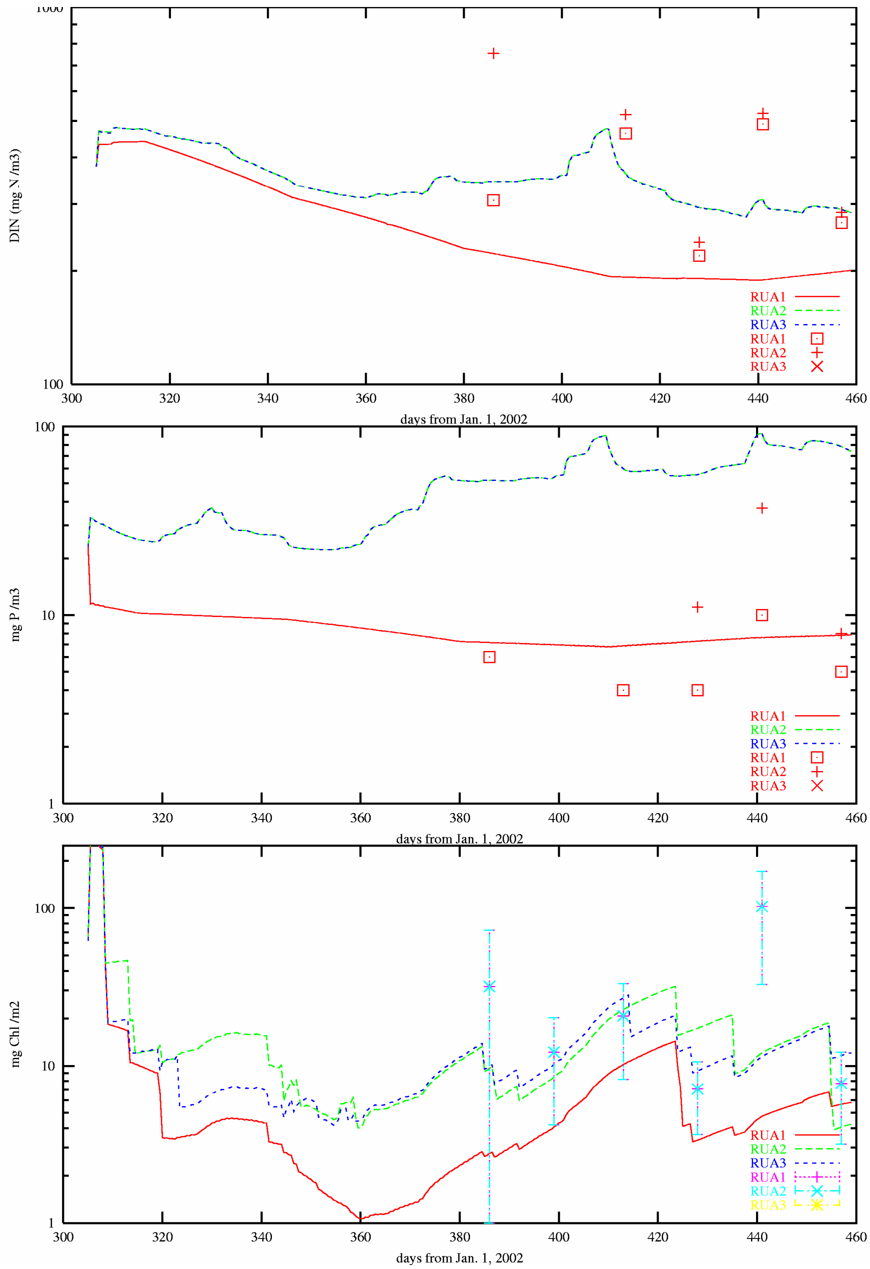


Figure 3.1: Model calibration for 2003 monitoring data (mean ± 2SE). Site 'RUA1' is included in Reach 2; reach number 8 includes the site 'RUA2' and reach number 9 includes the site 'RUA3' (see Appendix 4 for reach data).

Figure A5.1 shows flow hydrographs form 1988 to 2002. Visual inspection shows the variability of the flow hydrographs between years. Figure A5.2 illustrates the simulated densities of periphyton within each reach of the system for years between

1988 and 2002. The influence of spates is readily evident. The abundance of algae, effects of floods and recovery rate is also most strongly dependent on the slope of the reaches – with a low slope reach, such as Wardells Bridge, showing highest biomass levels. Two other features are also evident: periphyton densities are often somewhat higher downstream of the Makoura than they are upstream of this tributary. Secondly, summertime periphyton densities are predicted to vary substantially year-to-year.

For each reach in each summer (modelled from December 1st to March 31st), we have calculated the number of days on which periphyton 'nuisance' densities are predicted to exceed 100 mg Chl *a* m^{-2} (note: we have chose a slightly more conservative value here than the 120 mg Chl *a* m^{-2} used in the guidelines). (Table 3.1). These data showed that: (i) no nuisance growths were predicted at sites upstream for the entire 15 year modelling period (Note: this includes predictions for the monitoring RUA1 site); (ii) nuisance growths did occur at Wardells Bridge in 6 of the 15 years; (iii) duration of the nuisance growths at Wardells Bridge ranged from 3.5d to 35d, with most being of around 5d; and (iv) the nuisance growths appear to predominantly occur in the early summer period (see Fig. A5.2). The frequency and duration of predicted nuisance growths would be considered low, generally occurring for only a minimum fraction of the summer season.

Together these predictions indicate that the Ruamahanga River will experience algal growths approaching nuisance guideline thresholds. However, these nuisance thresholds will only be exceeded for short periods between successive flood events. Longer total bloom/days (21 – 35d) were only predicted to have occurred in 2 of the 15 years simulated.

A scenario was run without nutrient input to the Makoura Stream (Fig. 3,2). Comparing Figures 3.1 and 3.2 shows minimal differences in attached algal growth rates with addition of pond nutrients. The cumulative no-nutrient addition results showed largely comparable results to those summarised in Table 3.1 for duration with high algal abundances. This prediction is consistent with the high upstream nutrient concentrations resulting in near maximal growth rates relative to the hydrodynamic conditions. The strongest factor affecting differences between reaches was the slope, affecting growth rates and scour during floods. The maximum algal biomass is limited by the bed shear and the duration between significant flood events.

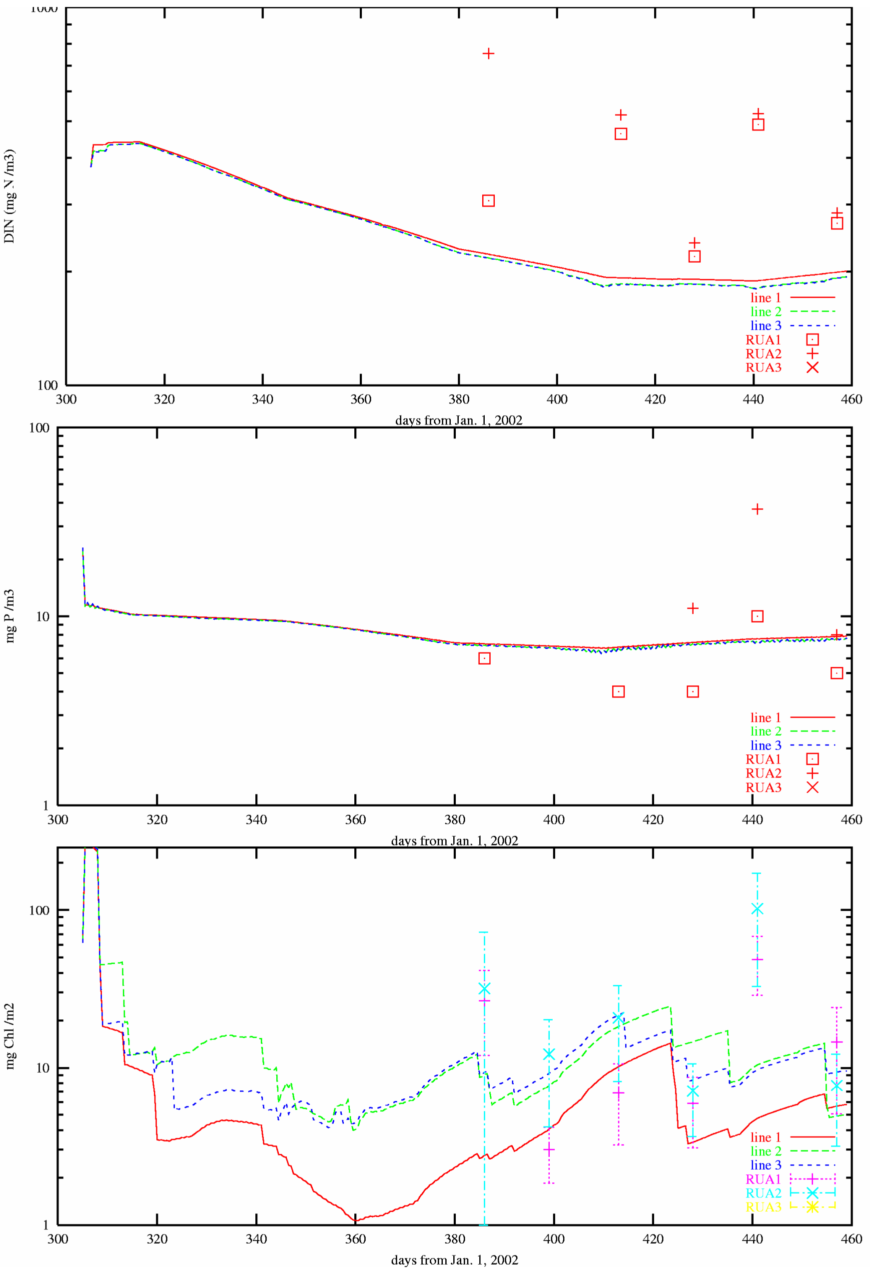


Figure 3.2: Model run for 2003 monitoring data (mean ± 2SE) with <u>no nutrient addition</u> from Masterton ponds. Site 'RUA1' is included in Reach 2 (Line 1); reach number 8 includes the site 'RUA2' (Line 2) and reach number 9 includes the site 'RUA3' (Line 3) (see Appendix 4 for reach data).

Table 3.1: Number of days in which the simulated periphyton abundance exceeds 100 mg Chl *a* m^{-2} during the period 1 December to 1 April for the summers 1988/1989 to 2002/2003. Reach number 2 includes the site 'RUA1'; reach number 8 includes the site 'RUA2' and reach number 9 includes the site 'RUA3'. Reach details provided in Appendix 3. Makoura Stream discharges to Reach 7.

Summer	**Days exceeding 100 mg Chl *a* m^{-2} by Reach number**								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
88/89	0	0	0	0	0	0	0	0	0
89/90	0	0	0	0	0	0	0.5	4	4.5
90/91	0	0	0	0	0	0	0	0	0
91/92	0	0	0	0	0	0	0	5.5	8
92/93	0	0	0	0	0	0	0	0	0
93/94	0	0	0	0	0	0	0	5.5	1.5
94/95	0	0	0	0	0	0	0	21	8.5
95/96	0	0	0	0	0	0	0	0	0
96/97	0	0	0	0	0	0	0	35.5	12
97/98	0	0	0	0	0	0	0	0	0
98/99	0	0	0	0	0	0	0	0	0
99/00	0	0	0	0	0	0	0	0	0
00/01	0	0	0	0	0	0	0	0	0
01/02	0	0	0	0	0	0	0	3.5	0
02/03	0	0	0	0	0	0	0	0	0

3.3. Limitations of model

The predictions from this model must be treated with caution for a number of reasons. The assumptions in parameterising the model included the assumption that the algae present in a large river would behave similarly to those in small streams – when marked differences include: (i) longer duration of flood events in rivers; (ii) larger boundary roughness (i.e., cobbles rather than gravels); and (iii) average river cross-sections are more satisfactory representations in streams. The latter factor is significant in the Ruamahanga where cross sections generally include a deeper thalwag section, which is visually low in algae, and extensive shallows where algal growths are visible. Because of the importance of light-attenuation, the model's failure to explicitly account for shallows leads to an under-prediction at such sites.

The inability of the model to adequately simulate the observed upstream and downstream growth rates in the late summer of 2003 is of some concern. If systemic (rather than a failure on this one occasion), it implies that the model is likely to have underestimated the frequency and magnitude of blooms – perhaps in all reaches. Nonetheless, the model does generally predict the differential growth rates observed in the early season – largely attributable to differences in reach slope. The late season growth may be the result of higher water clarity during this period than the model default values.

The model predicts marked differences in algal biomass behaviour between sites with different average slopes. This could be readily tested in monitoring programmes to quantify the responses under field conditions. The high frequency of flood events would require that such a monitoring programme be undertaken at a high frequency in order to reliably measure algal growth patterns.

4. Synthesis

The derivation of appropriate receiving water nutrient criteria should follow a 3 stage process in determining whether potential adverse effects may occur. These include: (i) determining the appropriate regional plan requirements and undertaking 'back-of-the-envelope' calculations relative to existing nutrient guidelines; (ii) obtaining scientific data to support the nature of the receiving habitat, nutrient loadings and potential for nuisance growths; and (iii) consideration of the need, feasibility and optimal treatment system to address potential effects.

The above processes have been followed in relation to the Masterton wastewater discharges to the Ruamahanga River. The RFPWR indicates that nuisance growths must be considered and the guidelines provide some guidance relative to potential nutrient thresholds – however, these do not constitute a requirement to meet these guideline values. The scientific analysis has shown that high nutrient levels are naturally present upstream and that the Ruamahanga River is generally dominated by a high frequency of significant flood events during summer periods. The modelling predictions have indicated that nuisance growths will occur downstream of the discharge, but will generally be of short duration. Furthermore, the algal growth model suggests that differences in river-bed slope are the major factor affecting algal abundance, rather than increased nutrient concentrations. Consideration of the mass loads indicates that the Masterton discharge is a significant phosphorus load to the river, but still markedly less than cumulative non-point loads.

Thus, while nutrient targets may be established for the Ruamahanga River and subsequently calculated for the wastewater discharge, the improvements in river condition in terms of reduction in extent and duration of nuisance algal biofilm growths will be slight. Improving river water quality by reduction in phosphorus load is desirable in the context of a component of overall phosphorus reduction measures (point and non-point sources). Thus the key consideration in relation to implementation of the wastewater treatment plant upgrade relates to cost-effective implementation of the phosphorus reduction systems.

5. References

Biggs, B.J.F. (2000). Eutrophication of streams and rivers: dissolved nutrient-chlorophyll relationships for benthic algae. *J North Am. Benthol. Soc. 19*: 17-31

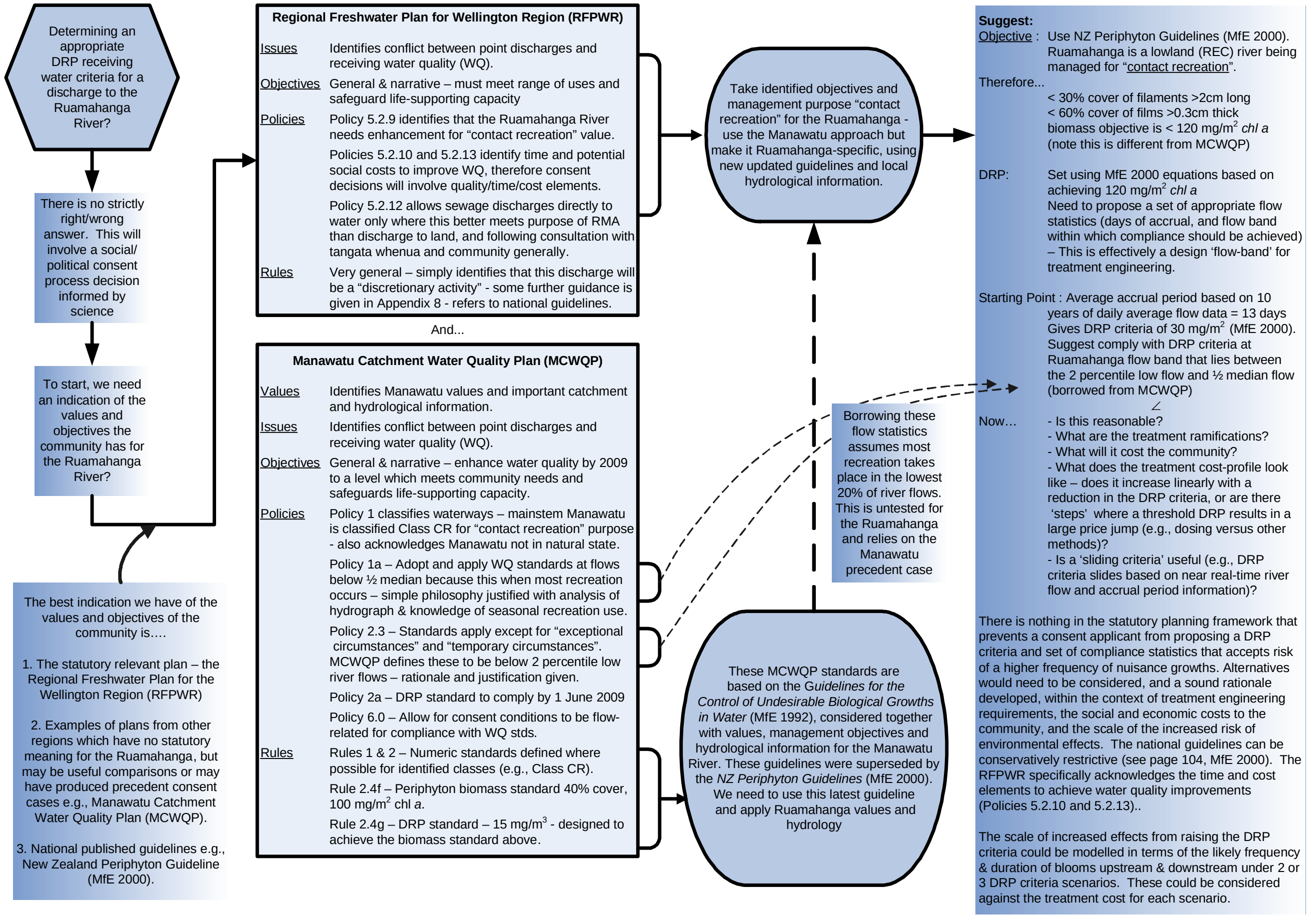
Broekhuizen, N.; Rutherford, J.C.; Quinn, J.M.; Scarsbrook, M.R. (2004). (submitted). Temporal dynamics of a stream periphyton & invertebrate community: observations, simulations and management implications. *Journal of the North American Benthological Society.*

Clausen, B.; Biggs, B.J.F. (1997). Relationships between benthic biota and hydrological indices in New Zealand streams. *Freshwater Biol. 38*: 327-342.

Hickey, C.W. (2004). Ruamahanga River: Nutrient and Algal Periphyton Monitoring in Relation to the Masterton Wastewater Discharge. BCH03207; Client Report No. HAM2003-154, NIWA report to Beca Ltd, Wellington, Hamilton.

MfE (2000). New Zealand periphyton guideline: detecting, monitoring and managing enrichment of streams. New Zealand Ministry for the Environment, Wellington.

Appendix 1: Flow chart of the process for proposing a DRP receiving water criteria for a wastewater discharge to the Ruamahanga River.



Determining an appropriate DRP receiving water criteria for a discharge to the Ruamahanga River?

There is no strictly right/wrong answer. This will involve a social/ political consent process decision informed by science

To start, we need an indication of the values and objectives the community has for the Ruamahanga River?

The best indication we have of the values and objectives of the community is….

1. The statutory relevant plan – the Regional Freshwater Plan for the Wellington Region (RFPWR)

2. Examples of plans from other regions which have no statutory meaning for the Ruamahanga, but may be useful comparisons or may have produced precedent consent cases e.g., Manawatu Catchment Water Quality Plan (MCWQP).

3. National published guidelines e.g., New Zealand Periphyton Guideline (MfE 2000).

Regional Freshwater Plan for Wellington Region (RFPWR)

Issues	Identifies conflict between point discharges and receiving water quality (WQ).
Objectives	General & narrative – must meet range of uses and safeguard life-supporting capacity
Policies	Policy 5.2.9 identifies that the Ruamahanga River needs enhancement for "contact recreation" value. Policies 5.2.10 and 5.2.13 identify time and potential social costs to improve WQ, therefore consent decisions will involve quality/time/cost elements. Policy 5.2.12 allows sewage discharges directly to water only where this better meets purpose of RMA than discharge to land, and following consultation with tangata whenua and community generally.
Rules	Very general – simply identifies that this discharge will be a "discretionary activity" - some further guidance is given in Appendix 8 - refers to national guidelines.

And...

Manawatu Catchment Water Quality Plan (MCWQP)

Values	Identifies Manawatu values and important catchment and hydrological information.
Issues	Identifies conflict between point discharges and receiving water quality (WQ).
Objectives	General & narrative – enhance water quality by 2009 to a level which meets community needs and safeguards life-supporting capacity.
Policies	Policy 1 classifies waterways – mainstem Manawatu is classified Class CR for "contact recreation" purpose - also acknowledges Manawatu not in natural state. Policy 1a – Adopt and apply WQ standards at flows below ½ median because this when most recreation occurs – simple philosophy justified with analysis of hydrograph & knowledge of seasonal recreation use. Policy 2.3 – Standards apply except for "exceptional circumstances" and "temporary circumstances". MCWQP defines these to be below 2 percentile low river flows – rationale and justification given. Policy 2a – DRP standard to comply by 1 June 2009 Policy 6.0 – Allow for consent conditions to be flow-related for compliance with WQ stds.
Rules	Rules 1 & 2 – Numeric standards defined where possible for identified classes (e.g., Class CR). Rule 2.4f – Periphyton biomass standard 40% cover, 100 mg/m^2 chl *a*. Rule 2.4g – DRP standard – 15 mg/m^3 - designed to achieve the biomass standard above.

Take identified objectives and management purpose "contact recreation" for the Ruamahanga - use the Manawatu approach but make it Ruamahanga-specific, using new updated guidelines and local hydrological information.

Borrowing these flow statistics assumes most recreation takes place in the lowest 20% of river flows. This is untested for the Ruamahanga and relies on the Manawatu precedent case

These MCWQP standards are based on the *Guidelines for the Control of Undesirable Biological Growths in Water* (MfE 1992), considered together with values, management objectives and hydrological information for the Manawatu River. These guidelines were superseded by the *NZ Periphyton Guidelines* (MfE 2000). We need to use this latest guideline and apply Ruamahanga values and hydrology

Suggest:

Objective : Use NZ Periphyton Guidelines (MfE 2000). Ruamahanga is a lowland (REC) river being managed for "contact recreation".

Therefore...

- < 30% cover of filaments >2cm long
- < 60% cover of films >0.3cm thick
- biomass objective is < 120 mg/m^2 *chl a*
- (note this is different from MCWQP)

DRP: Set using MfE 2000 equations based on achieving 120 mg/m^2 *chl a*

Need to propose a set of appropriate flow statistics (days of accrual, and flow band within which compliance should be achieved) – This is effectively a design 'flow-band' for treatment engineering.

Starting Point : Average accrual period based on 10 years of daily average flow data = 13 days

Gives DRP criteria of 30 mg/m^2 (MfE 2000).

Suggest comply with DRP criteria at Ruamahanga flow band that lies between the 2 percentile low flow and ½ median flow (borrowed from MCWQP)

∠

Now…
- Is this reasonable?
- What are the treatment ramifications?
- What will it cost the community?
- What does the treatment cost-profile look like – does it increase linearly with a reduction in the DRP criteria, or are there 'steps' where a threshold DRP results in a large price jump (e.g., dosing versus other methods)?
- Is a 'sliding criteria' useful (e.g., DRP criteria slides based on near real-time river flow and accrual period information)?

There is nothing in the statutory planning framework that prevents a consent applicant from proposing a DRP criteria and set of compliance statistics that accepts risk of a higher frequency of nuisance growths. Alternatives would need to be considered, and a sound rationale developed, within the context of treatment engineering requirements, the social and economic costs to the community, and the scale of the increased risk of environmental effects. The national guidelines can be conservatively restrictive (see page 104, MfE 2000). The RFPWR specifically acknowledges the time and cost elements to achieve water quality improvements (Policies 5.2.10 and 5.2.13)..

The scale of increased effects from raising the DRP criteria could be modelled in terms of the likely frequency & duration of blooms upstream & downstream under 2 or 3 DRP criteria scenarios. These could be considered against the treatment cost for each scenario.

Appendix 2: Hydrodynamic characteristics for Manawatu River and Ruamahanga River (Wardells Bridge) (PSIM run in TIDIDA; Maurice Duncan, NIWA).

Table A2.1: Ruamahanga River Flow at Wardell’s Bridge (1989-2003) (from Beca).

	All Data (m^3/s)	Summer Data Only (m^3/s)
Maximum	471.69	458.38
Median	13.01	8.30
Half-Median	6.51	4.15
5 Percentile	3.18	2.65
2 Percentile	2.55	2.34
Minimum	1.86	1.86

Table A2.2: Flow statistics for Manawatu and Ruamahanga rivers. FRE3 is the flood exceeding 3X the median flow (either on an annual or summer basis). Period between floods = ‘filter period’, interval period between flood peaks at which the ‘flood’ is assumed to be a single event.

	days Period between floods	# Floods	floods/yr FRE3	hours flood	hours/year h/y	hours/flood h/f	days Interflood (days of accrual)
Manawatu	1	284	16.5	18072	1048	63.6	22.2
17.24 yrs	2	274	15.9	17448	1012	63.7	23.0
median	3	258	15	16488	956	63.9	24.4
67 m3/s	4	246	14.3	15648	907	63.6	25.6
daily	5	236	13.7	14880	863	63.1	26.7
average	6	224	13	13968	810	62.3	28.1
	7	212	12.3	13128	761	61.9	29.7
			floods/summer				
Summer	1	145	8.4				21.8
median 44.7 m3/s	5	121	7				26.1
Manawatu	1	476	27.6	17135	993	36	13.2
17.24 yrs	2	431	25	15654	907	36.3	14.6
median	3	401	23.2	14235	825	35.5	15.7
67 m3/s	4	361	20.9	13175	763	36.5	17.5
instant	5	342	19.8	12446	721	36.4	18.4
data	6	328	19	11102	644	33.8	19.2
	7	304	17.6	9862	571	32.4	20.7
Summer	1	245	14.2				12.9
median 44.7 m3/s	5	178	10.3				17.8
Ruamahanga	1	333	23.6	21216	1505	63.7	15.4
dataset = 14.1 yrs	2	322	22.8	20424	1449	63.4	16.0
median 12.3 m3/s	3	301	21.4	19224	1364	63.8	17.1
use daily average data	4	281	19.9	17904	1270	63.7	18.3
	5	268	19	16680	1183	62.2	19.2
	6	252	17.9	15744	1117	62.5	20.4
	7	238	16.9	14808	1051	62.2	21.6
Summer	1	188	13.3				13.8
median 6.56 m3/s	5	149	10.6				17.3
Ruamahanga	1	616	43.7	19341	1372	31.4	8.4
dataset = 14.1 yrs	2	533	37.8	17258	1224	32.4	9.7
median 12.3 m3/s	3	480	34.1	15370	1090	32	10.7
use instantaneous data	4	424	30.1	13982	992	33	12.1
	5	391	27.7	12611	895	32.2	13.1
	6	367	26	11629	825	31.7	14.0
	7	339	24	10861	770	32	15.1
Summer	1	331	23.5				7.8
median 6.56 m3/s	5	207	14.7				12.4

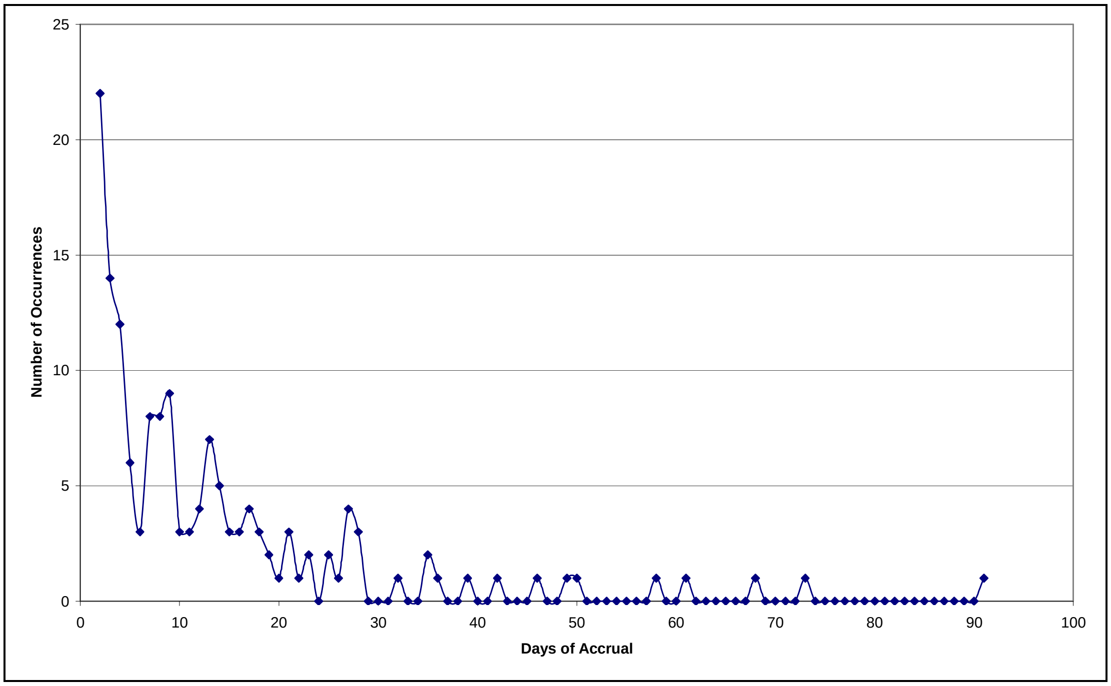


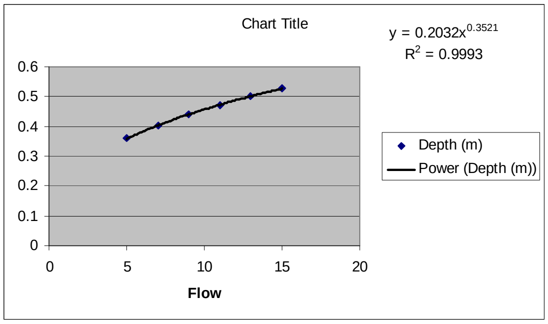
Figure A2.1: Frequency of accrual period durations for summer (1989-2003) (Beca data).

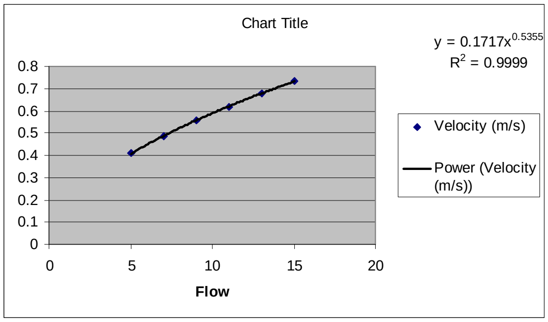
Appendix 3: Cross-section data from Ruamahanga River at Wardells Bridge (I. Jowett, NIWA)

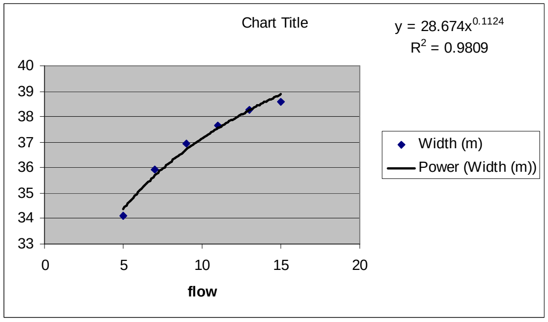
Reach Geometry Evaluation: Ruamahanga_Wardells

Reach length : 356.00 m

Flow (m3/s)	Width (m)	Depth (m)	Velocity (m/s)	Area (m2)	Wetted Perimeter (m)	Froude no.	Pool %	Run %	Riffle %
5	34.1	0.36	0.41	12.3	34.3	0.231	41.0	51.6	7.3
7	35.9	0.40	0.49	14.4	36.1	0.251	35.0	51.7	13.3
9	36.9	0.44	0.56	16.2	37.2	0.265	30.4	52.4	17.2
11	37.7	0.47	0.62	17.8	37.9	0.280	26.0	54.5	19.4
13	38.3	0.50	0.68	19.2	38.5	0.307	19.9	56.7	23.4
15	38.6	0.53	0.73	20.4	38.9	0.311	18.7	54.8	26.4







Appendix 4: Summary characteristics of reaches used in benthic algal modelling.

Table A4.1: Details of the reaches defined within the model. Information is derived from the sheet Masterton Oxidation Ponds Long-section for Gravel Extraction Consent. The column H.A.D. refers to the datum heights reported on that sheet. The column Model elevation refers to the elevations reported to the model (from which reach-specific slopes are derived). [1]Where a cross-section elevation was not reported, linear interpolation was used to derive a value for the model. Reach number 2 includes the site 'RUA1' from the 2003 monitoring; reach number 8 includes the site 'RUA2' and reach number 9 includes the site 'RUA3'. Makoura Stream discharges to Reach 7.

Cross-section	Distance (m)	H.A.D. 75 m	Dist from upstream	Model elevation (m)	Slope (%)
1	4975	95.83	0	95.83	0.21
2	4321	94.43	654	94.43	0.22
3	3817	93.31	1158	93.31	0.33
4	3164	91.18	1811	91.18	0.056
5	2914		2061	[1]91.04	0.054
6	2504	90.82	2471	90.82	0.28
7	2190		2785	[1]89.93	0.29
8	1960	89.27	3015	89.27	0.074
9	1476	88.91	3499	88.91	0.38
10	1010	87.16	3965	87.16	0.91
11	743	84.72	4232	84.72	

Appendix 5: Ruamahanga River flow and benthic algal biomass simulations for 1988 to 2002.

Figure A5.1: Instantaneous flow records for Ruamahanga River at Wardells Bridge. Each plot shows summer data from 1 Nov (day 305) to 1 April (day 460) of the following year.

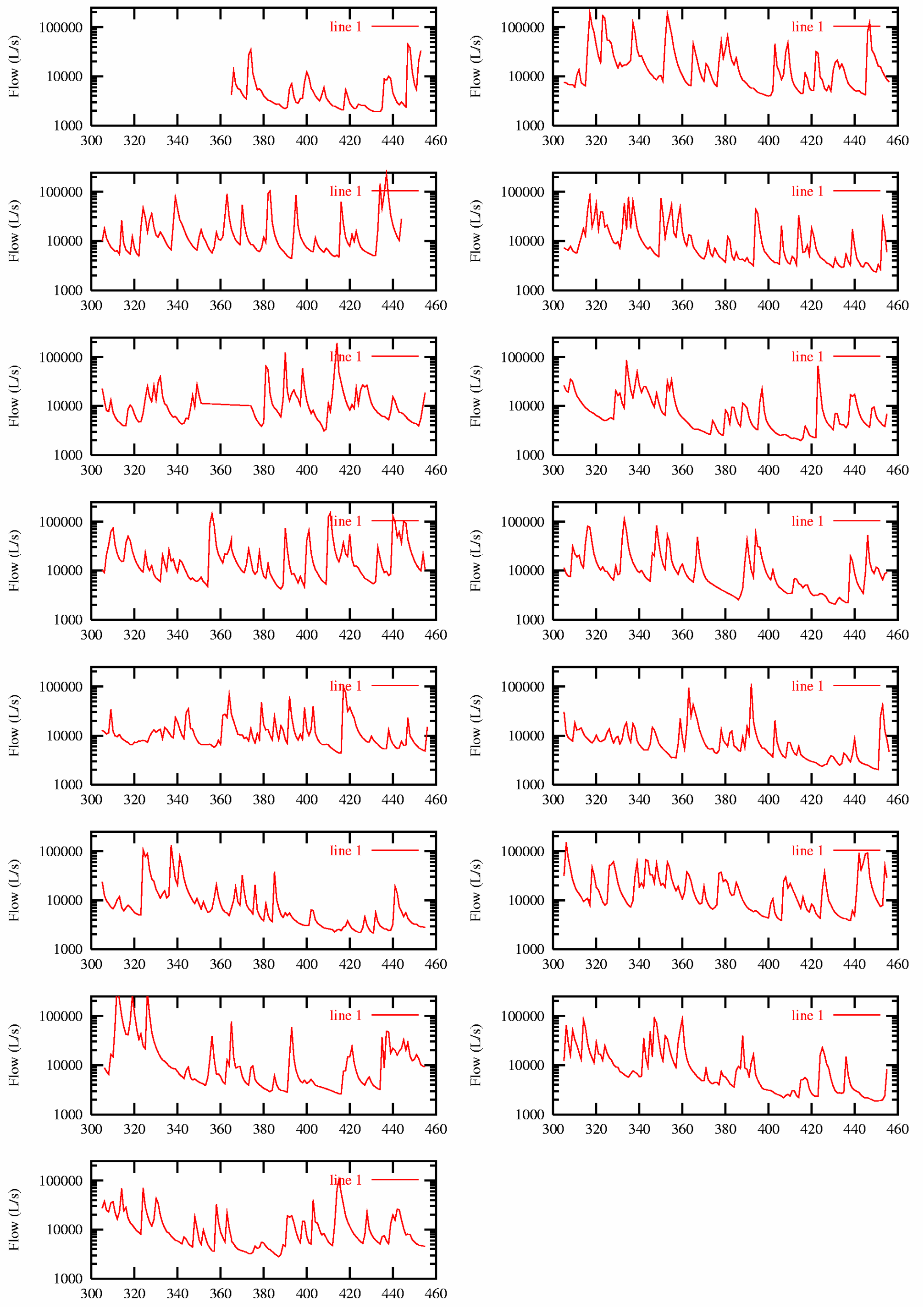
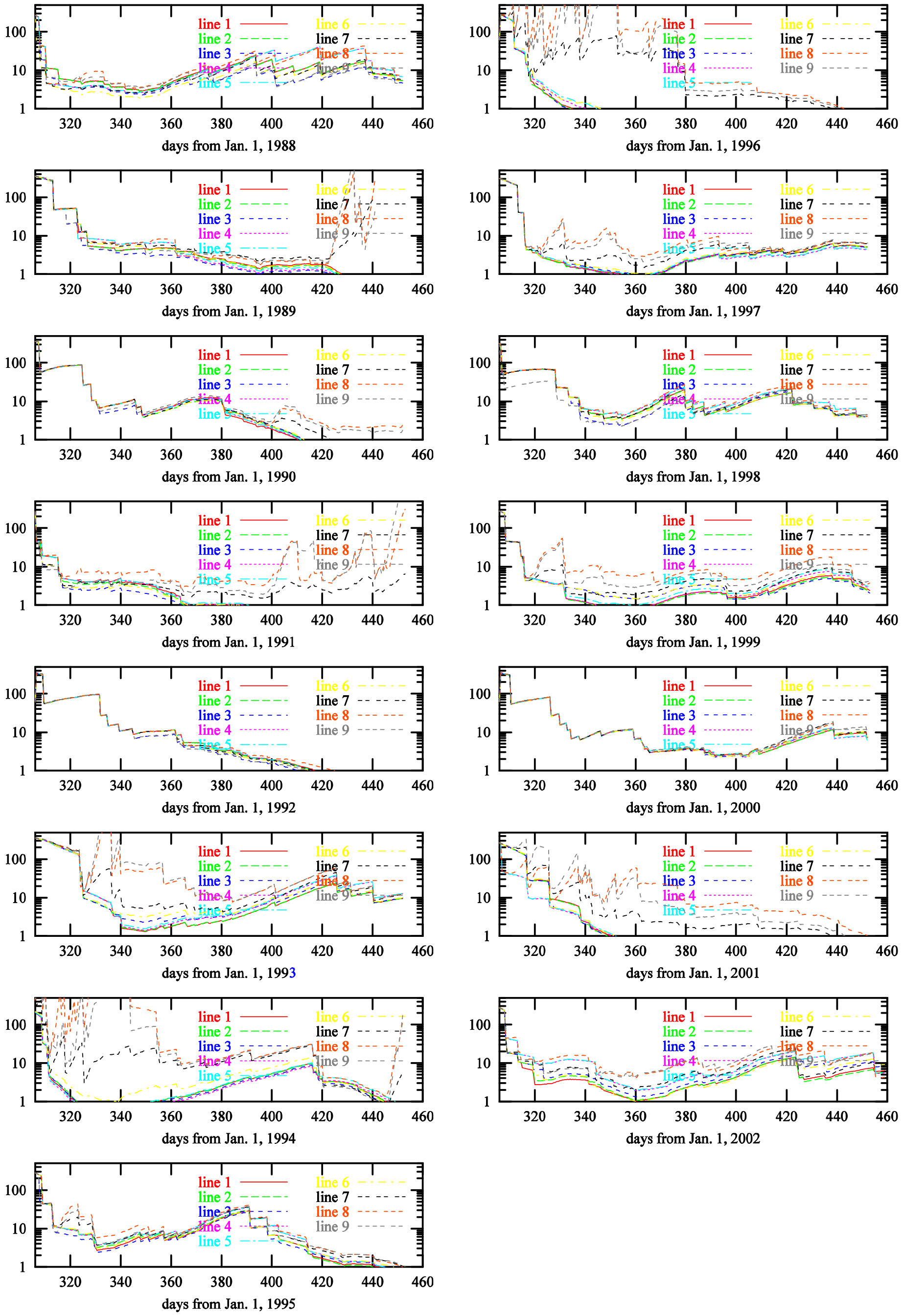


Figure A5.2: Modelled benthic algal biomass in the Ruamahanga River from 1988 to 2002. Reach number 2 (termed ‘Line 2’) includes the site ‘RUA1’ from the 2003 monitoring. Reach number 8 includes the site ‘RUA2’ and reach number 9 includes the site ‘RUA3’. See Appendix 4 for reach data.



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