BEFORE THE HEARINGS PANEL

IN THE MATTER of hearings on submissions concerning the Proposed One Plan notified by the Manawatu-Wanganui Regional Council

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SUPPLEMENTARY EVIDENCE OF DR BARRY JOHN FRANKLYN BIGGS
FOR THE END OF HEARING REPORT (WATER)
ON BEHALF OF HORIZONS REGIONAL COUNCIL

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1. PART ONE: INTRODUCTION AND EXECUTIVE SUMMARY

1. I have prepared this report as further supplementary evidence to my Section 42A report and Supplementary Evidence dated November 2009. It has been compiled in response to issues raised during the Water Hearing relating to evidence presented by myself and other experts.

2. This evidence is in three parts:
Part one: this introduction and executive summary
Part two: commentary and further evidence on:

- the environmental benefits (in terms of periphyton biomass and benthic invertebrate communities) of the nutrient management regime of the Proposed One Plan (POP) including proposed Rule 13-1;
- the considerations and management implications of trophic relationships between trout and periphyton biomass; and
- response to issues raised by submitters' experts on nutrients and periphyton.

Part three: corrections to my original evidence (revised track changes version appended).

2. EXECUTIVE SUMMARY OF FURTHER SUPPLEMENTARY EVIDENCE

3. During the Water Hearing two key issues were raised which I was asked to provide further evidence and commentary on. Briefly these issues were: 1) determine the in-stream environmental benefits of nutrient management under the combined nutrient management approach of the POP, including Proposed Rule 13-1; and 2) discuss the management implications/considerations of trophic relationships between periphyton biomass and trout abundance/health.

4. Additionally, some supplementary evidence was presented at the Hearing by Dr Mike Scarsbrook on the relationship between nutrients and periphyton biomass and Associate Professor Russell Death on the applicability of the periphyton model to the Horizons' Region. I respond briefly to these statements.

5. All commentary on the environmental benefits of the POP nutrient management approach and the issues raised by submitters' experts should also be read in conjunction with the End of Hearing Reports from Horizons.

6. I used a statistical model to predict the maximum periphyton biomass under several nutrient-loading scenarios (including the standard load limit) for the Manawatu at

Hopelands site. Under the **Current state** scenario, the Manawatu River at Hopelands is already significantly enriched (eutrophic) and due to the infrequent occurrence of high flow events that enable flushing of the river, accrues significant periphyton biomass which will exceed the periphyton guidelines, degrade benthic invertebrate communities and be visually conspicuous. My predictions of the degradation of invertebrate communities are reflected in the measured MCI data for the site.

7. Under all the intensification scenarios, periphyton growth in the Manawatu River is likely to increase moderately to greatly, and reach biomass levels that are often considered to be hyper-eutrophic, aesthetically undesirable, and reduce the biodiversity of benthic invertebrate communities (with negative implications for fish, particularly trout). All the nutrient reduction scenarios will result in significantly lower periphyton maximum biomass and a reduced duration of high biomass events that exceed the periphyton guideline. Also, all scenarios are likely to be effective for increasing in-stream benthic invertebrate biodiversity, with the greatest gains being for adoption of the '**Ideal**' loadings.

8. Adoption of any of the nutrient reduction scenarios is likely to not only prevent further increases in periphyton biomass (and associated reductions in overall in-stream biodiversity) in other target zones in the Region, but also lead to significant (and possibly greater) reductions in maximum periphyton biomass than those predicted for the Manawatu River at Hopelands case study site.

9. The combined POP nutrient management approach would provide the most significant benefits to in-stream conditions in low order streams in small catchments, such as the tributaries of the upper Manawatu. This is because these streams are most intimately linked with the land (eg. a significant proportion of the stream waters are usually derived directly as seepage and drains), these catchments are generally steeper so run-off directly into the streams is more immediate, and the stream beds are coarser gravel/cobble materials which provide better habitat for periphyton and benthic invertebrates. So, provisions relating to whole farm losses such as good on-farm management of effluent, controls over 'hot-spots' of nitrogen leaching, and fencing of streams in the mid and upper catchments will have the highest benefits, and these benefits will be most strongly realised locally.

10. The degree of transferability of these predictions to other target catchments in Horizons' Region is high as periphyton has a similar and predictable response to given nutrient loadings worldwide. The main factors influencing local transferability of the concepts are:

1) regional variations in the frequency of flood/fresh events, which will alter the mean days of accrual; and 2) variations in bed sediment composition. Periphyton communities in Horizons' Region are the same as those found widely across New Zealand, and globally. Many studies elsewhere in the world have now arrived at similar conclusions to my own (eg. high periphyton biomass that can adversely affect ecosystem health occurs at mean DRP levels > 15 mg/m^3). The high transferability of similar relationships for lakes (except involving phytoplankton, not benthic algae/periphyton) is why lake eutrophication models originally developed in Canada are now used all over the world to assist with lake management.

3. PART TWO: RESPONSE TO ISSUES RAISED DURING THE WATER HEARINGS

In-stream environmental benefits of the POP combined nutrient management approach

11. Further clarification of the association between periphyton biomass and other in-stream life has been requested and I offer the following commentary in response: at sites where maximum periphyton biomass is predominantly < 50 mg chlorophyll *a*/m^2 the benthic invertebrate community is very diverse and often contains quite large numbers of rare and/or environmentally sensitive taxa such as stoneflies and some species of mayflies (usually QMCI[1] $\geq$ 8 see Table 1). As maximum periphyton biomass increases to around 120 mg chlorophyll *a*/m^2, the more environmentally sensitive taxa become less abundant (particularly stoneflies) and therefore the overall community diversity decreases (usually QMCI of 6 - 7). Caddisfly larvae are often at high abundance and midges, worms and snails start to increase in relative abundance. This is often the best habitat for trout, but not so much for native fish. As maximum biomass increases for prolonged periods (eg., > 4 weeks/year) well beyond 200 mg chlorophyll *a*/m^2, benthic invertebrate diversity declines still further and communities become progressively dominated by midges, worms and snails (often QMCI < 6). These conditions provide poor habitat for most types of fish. Conditions at this level of periphyton are also usually aesthetically displeasing, particularly in shallow streams (see Photos 1d – 1f).

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[1] QMCI: Quantitative Macroinvertebrate Community Index

Table 1: Interpretation of MCI type biotic indices (reproduced from Stark and Maxted, 2007)

Stark & Maxted (2004, 2007) quality class	Stark (1998) descriptions	MCI	QMCI
Excellent	Clean water	> 119	> 5.99
Good	Doubtful quality or possible mild pollution	100-119	5.00-5.99
Fair	Probable moderate pollution	80-99	4.00-4.99
Poor	Probable severe pollution	< 80	< 4.00

12. In the following paragraphs I focus on the questions asked by the Hearing Panel and Horizons staff relating to further describing the specific in-stream benefits of the POP nutrient management approach, including Proposed Rule 13-1.

13. I have been provided with several scenarios for the upper Manawatu catchment to use as the case study for determining the in-stream environmental benefits of various nutrient management approaches. The scenarios include both intensification and nutrient reduction regimes. I have particularly focused on the comparison between the current state and the predicted state under Rule 13-1 with no land use change, as requested by the Hearing Panel. It is important to note that the definition for this scenario includes nutrient reductions resulting from the POP combined approach to nutrient management (ie. including reductions via point-source discharges and highly erodible land through the Sustainable Land Use Initiative (SLUI) programme).

14. The scenarios provided by Horizons staff[2] (Table 2) were defined as:

<u>Intensification scenarios:</u>

i. **Fonterra Year 1 load**[3] – annual N load calculated from Year 1 of Fonterra's proposed N loss limits for Table 13-2.

ii. **1200 kg MS/ha load <u>and</u> LUC expansion load** – annual load calculated by Clothier *et al*. (2007) using N loss limits predicted from intensification of land currently in dairying (increasing production from an average of 1,000 to 1,200 kg

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[2] Full scenario descriptions are included in the Horizons End of Hearing Report.

MS/ha) and the annual load using N losses predicted from expansion of dairying onto all LUC Class 3 or better land under current management practices.

iii. **1200 kg MS/ha load <u>or</u> LUC expansion load** – Combined annual load calculated by Clothier *et al*. (2007) using N loss limits predicted from intensification of land currently in dairying (increasing production from an average of 1000 to 1,200 kg MS/ha). Or annual load calculated by Clothier *et al*. (2007) using N losses predicted from expansion of dairying onto all LUC Class 3 or better land under current management practices. As per the modeling of Clothier *et al.* (2007) above combining both scenarios. For either of these scenarios the appropriate load to model is 877 tonnes/year

iv. **Rule 13-1 Year 20 load** – annual load calculated by Clothier *et al.* (2007) using full allocation of N loss limits proposed in the proposed Rule 13-1 Year 20 requirements. This model assumes every hectare in the catchment is leaching at the full loss rates (Year 20) from Table 13.2.

v. **Current state** – measured annual load based on the calculation of Roygard & McArthur (2008).

<u>Nutrient reduction scenarios:</u>

vi. **Rule 13-1 no land use change** – implementation of proposed Rule 13-1 Year 20 nitrogen loads for all existing intensive land uses depending on LUC class (dairy, cropping and horticulture).

vii. **1/3 reduction** – annual load based on assumed 1/3 reduction from current state (both dairying and sheep and beef) using potential mitigation options as described by Clothier *et al.* (2007) for N, Parfitt *et al.* (2007) for P and Roygard & McArthur (2008) for point source BMP reductions. This model assumes no change in land use or intensity.

viii. **Standard load limit** – annual load calculated from POP standards for SIN (444 mg/m^3) and DRP (10 mg/m^3) using the calculation methods of Roygard & McArthur (2008).

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[3] Evidence of Gerard Willis, attachment 4, page 43 (Table 13-2, Year 1 Value A).

ix. **Ideal load** – annual load calculated from my recommended nutrient standards for SIN (110 mg/m^3) and DRP (10 g/m^3) using the load calculation methods of Roygard & McArthur (2008).

15. Table 2 below summarises the nutrient loads and resultant average concentrations from each of these scenarios which were used to predict the periphyton biomass responses discussed in this evidence. The method for determining periphyton biomass from nutrient loads used the same five step process outlined in my S42A report (paragraph 60) and is not repeated here. Table 3 details the periphyton biomass under nitrogen and phosphorus limited conditions for each of the nutrient management scenarios.

Table 2: Nutrient loads and concentrations for various intensification and nutrient reduction scenarios for the upper Manawatu River at Hopelands.

Intensification scenarios	**N load tonnes / year**	**N conc. g/m^3**	**P load[4] tonnes / year**	**P conc. g/m^3**
Fonterra Year 1	1,080	1.284	21	0.023
1,200 kg MS/ha load AND LUC dairy expansion load	1,009	1.200	21	0.023
1,200 kg MS/ha load OR LUC dairy expansion load	877	1.044	21	0.023
Rule 13-1 Year 20 load (full allocation of N losses Table 13.2)	755	0.898	21	0.023
Current state	745	0.875	21	0.023
Nutrient reduction scenarios	**N load tonnes / year**	**N conc. g/m^3**	**P load tonnes / year**	**P conc. g/m^3**
Rule 13-1 Year 20 load **no change** in current land use areas	536	0.637	12.6	0.014
1/3 reduction	490.1	0.583	12	0.013
Standard load limit	358	0.426	8.1	0.009
Ideal load	89	0.106	8.1	0.009

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[4] Phosphorus loads for these scenarios cannot be accurately calculated because any reductions in phosphorus as a result of point-source or SLUI improvements may be offset by an unknown degree of increased phosphorus load from intensification. Because of the potential for no net benefit (or an increase) in P loads, we have opted to apply the current state phosphorus loads for the intensification scenarios.

Table 3: Predicted instantaneous SIN and DRP concentrations and periphyton biomass for the Manawatu at Hopelands under different nutrient loading scenarios. MDA: mean days of accrual (updated from 36 days based on a larger flow dataset). Nutrient concentrations are in mg/m^3. Chlorophyll *a* biomass is in mg chlorophyll *a* /m^2. Chl (N): predicted maximum periphyton biomass under nitrogen-limited conditions. Chl (P): predicted maximum periphyton biomass under phosphorus-limited conditions. SIN concentrations rounded to 10 mg/m^3, DRP concentrations rounded to 1 mg/m^{-3}, Chl concentrations rounded to 10 mg/m^2.

Scenario	**Manawatu River at Hopelands (MDA: 39 d)**			
Intensification scenarios	**SIN** mg/m^3	**DRP** mg/m^3	**Chl (N)**	**Chl (P)**
Fonterra Year 1	1,280	23	1,220	550
1200 kg MS/ha load AND LUC dairy exp. load	1,200	23	1,180	550
1200 kg MS/ha load OR LUC dairy exp. load	1,040	23	1,100	550
Rule 13-1 Year 20 load – full allocation N losses	900	23	1,020	550
Current state	870	23	1000	550
Nutrient reduction scenarios	**SIN** mg/m^3	**DRP** mg/m^3	**Chl (N)**	**Chl (P)**
Rule 13-1 Year 20 load – no land use change	640	14	860	430
1/3 reduction	580	13	820	410
Standard load limit	430	9	700	340
Ideal load	110	9	350	340

16. A key question now becomes: “what would the rivers ‘look like’ under the different scenarios?” In the following paragraphs I describe expected conditions at the case study site ‘Manawatu at Hopelands’, under the current state vs. nutrient intensification and nutrient reduction scenarios for periphyton (note: nuisance macrophyte growth is not included) and the implications for benthic invertebrates (listed in increasing order of potential instream benefits; data in Table 3). Note that the ranges in maximum periphyton biomass being discussed are defined by the predictions of the nitrogen vs. phosphorus model. Because of the way nutrient limitation switches between these nutrients, it is advisable to treat the most likely maxima in biomass as existing somewhere between these two limits. See Photos (1a-f) for a pictorial of what the rivers might periodically look like for different levels of maximum periphyton biomass.

Photo 1a: Chlorophyll *a* = 80 mg/m^2

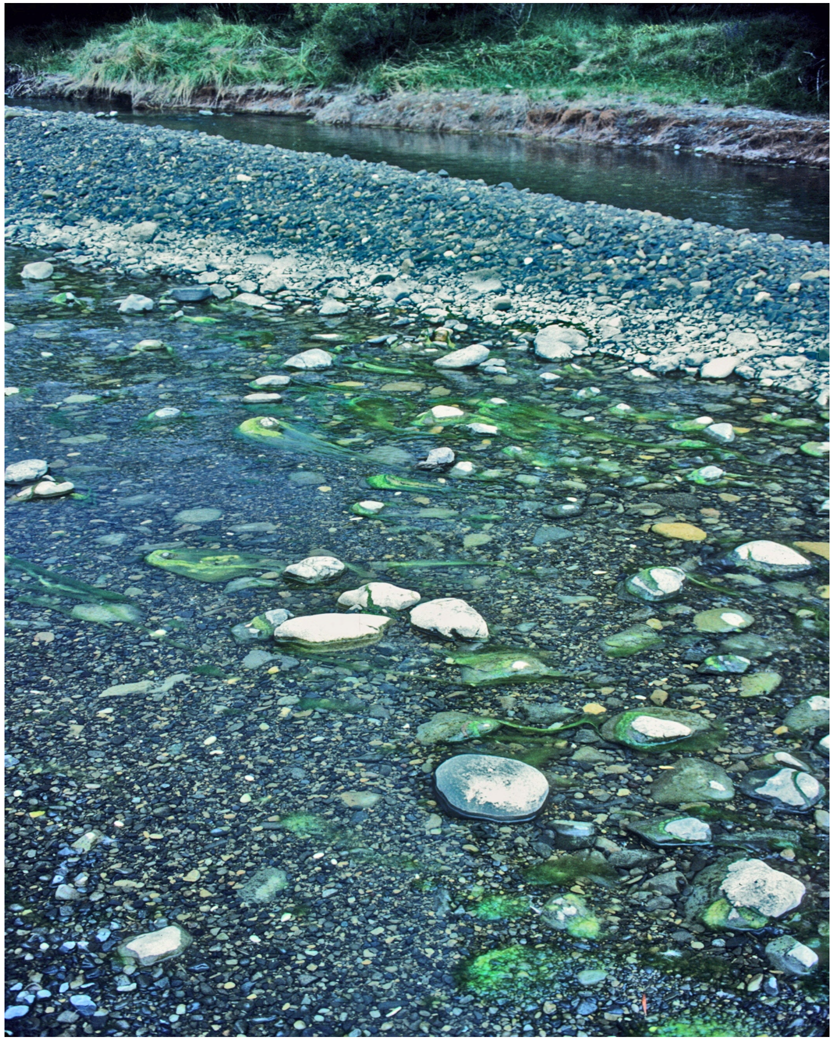


Photo 1b: Chlorophyll *a* = 120 mg/m^2

Photo 1c: Chlorophyll *a* = 160 mg/m^2

Photo 1d: Chlorophyll *a* = 300 mg/m^2

Photo 1e: Chlorophyll *a* ~ 900 mg/m^2

Photo 1f: Chlorophyll *a* > 1,500 mg/m^2

17. **Current State:** the Manawatu at Hopelands site is eutrophic (Figure 1), displaying prolonged periods of extensive slime cover of the riverbed during periods of stable flow, at any time of the year. Based on the flow hydrographs for this river (and associated duration of baseflows), and Biggs (2000b), biomass exceeding 200 mg/m^2 chlorophyll *a* could occur for 4-6 weeks per year in 3 out of 4 years under current conditions, occasionally reaching ~ 900 mg/m^2 chlorophyll *a* (see Photo 1e). Filamentous green algae are usually a dominant component of the slime, and re-growth is rapid after floods. Benthic invertebrate communities with a moderate, and sometimes low, diversity according to my estimates (eg. usually QMCI < 6, and sometimes < 5 or MCI < 100) and as reflected in the measured MCI data for Hopelands (see figure 34, page 192 of Kate McArthur's S42A report), and a low abundance of 'clean water' taxa. These effects will be most conspicuous, and likely have the greatest ecological implications in the 2nd-3rd order headwater and tributary streams for the catchment, due to these being shallower, steeper and having better cobble substrate to host periphyton attachment and growth.

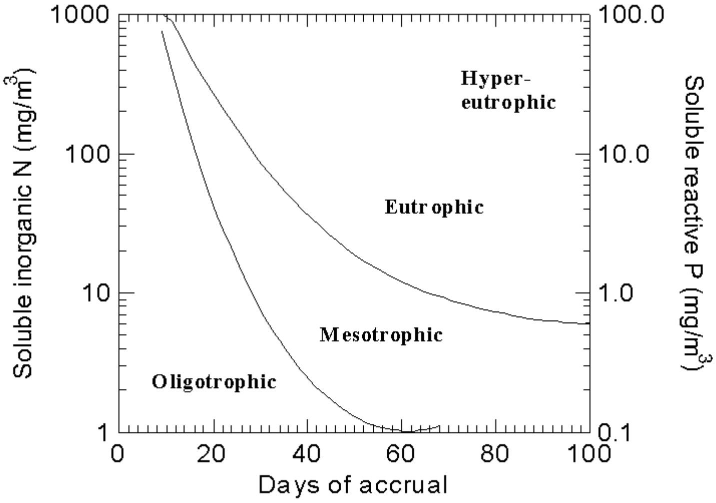


Figure 1: Nomograph showing trophic state (rivers) against days of accrual and soluble nitrogen (SIN) and phosphorus (SRP) concentrations (modified from Biggs, 2000a to include hyper-eutrophic state).

Nutrient intensification scenarios

18. Differences in the in-stream effects of the **Fonterra Year 1, 1,200 kg MS/ha, LUC dairy expansion load,** and **Rule 13-1 Year 20 load (full allocation)** scenarios are all minor and based only on reductions in N loading. If periphyton growth at this site were always to be controlled by P then few differences in in-stream conditions would be expected

amongst the scenarios and there would be few changes compared with the **Current state**. Maximum periphyton biomass during periods of prolonged low flow would be 500-600 mg/m^2 chlorophyll *a* and would look somewhat like Photos1d-1e. Benthic invertebrate communities would have a moderate, and sometimes low, diversity (eg. QMCI < 6 and often < 4 or MCI < 100).

19. However, at times when there is ample phosphorus in the water, and thus nitrogen is the primary nutrient controlling periphyton growth, differences in periphyton biomass would be observed according to the different N-loading scenarios. For example, mean SIN concentrations would be as high as 1,280 mg/m^3 under the **Fonterra Year 1**, and reduce to 900 mg/m^3 under the **Rule 13-1 Year 20 – full allocation N losses** scenario. Under all these scenarios (where nitrogen was controlling periphyton growth), biomass of periphyton would be worse than under the **Current state** (particularly for the first two scenarios) and the site could be classified as ‘hyper-eutrophic’ (Figure 1), with filamentous green algae being the dominant component of the periphyton. A difference in effect would be observable amongst the scenarios, with the highest biomass development under the **Fonterra Year 1** loading, where maximum periphyton biomasses approaching that shown in Photo 1f would be possible, particularly during long accrual periods; grading down to those represented by Photo 1e under the **Rule 13-1 Year 20 load – full allocation N losses**. Based on the site hydrographs, and Biggs (2000b), biomass greatly exceeding 200 mg chlorophyll *a*/m^2 could occur for > 8 weeks/yr for 3 out of 4 years under all these scenarios. If such biomasses occurred, then benthic invertebrate communities would have a low diversity (eg. usually QMCI < 4 or MCI < 80), comprising predominantly midges and worms.

20. In summary, under all these intensification scenarios, periphyton biomass is likely to reach levels for prolonged periods in the Manawatu River at Hopelands that are indicative of eutrophic to hyper-eutrophic conditions (Figure 1), with periphyton mats dominated by filamentous green algae which are often considered aesthetically undesirable by the public, and which will significantly reduce the biodiversity of benthic invertebrate communities in the river, with negative implications for fish, particularly trout.

Nutrient reduction scenarios

21. **Rule 13-1, without land use change and 1/3 reduction:** these two scenarios are predicted to have very similar outcomes in terms of loadings and will result in a modest improvement (ie. ~ 15% reduction) in maximum biomass compared with the **Current**

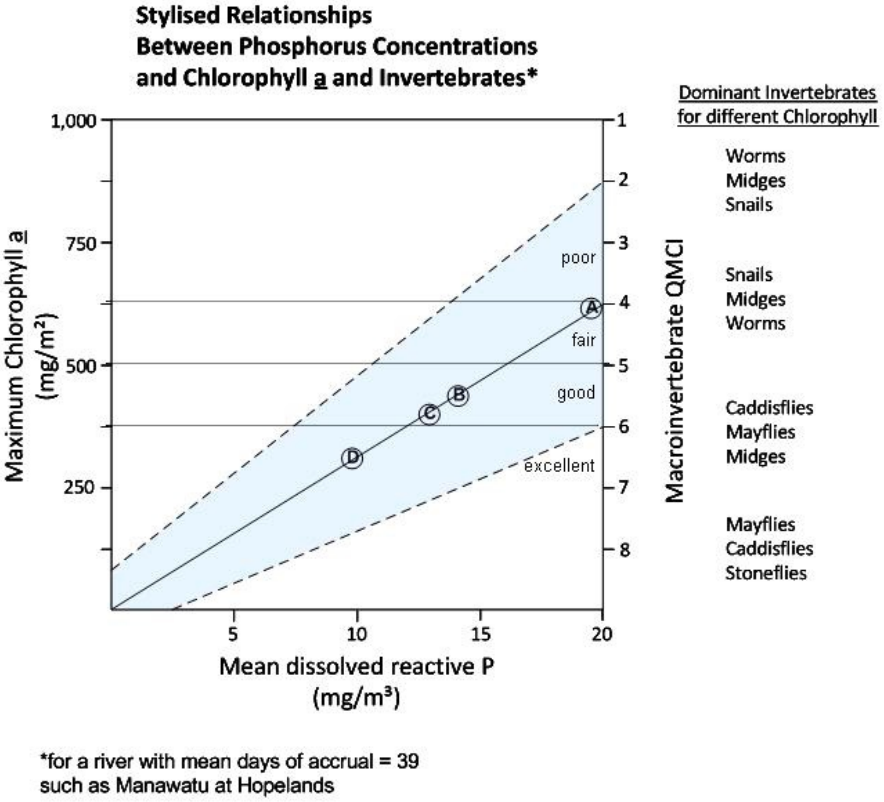
state. The site would still be classified as 'eutrophic', but filamentous green algae would be much less common than under the **Current state** or any of the 'Intensification' scenarios. Based on the hydrographs for this site, and Biggs (2000b), biomass could exceed 200 mg/m^2 chlorophyll *a* for 2-4 weeks/year in 3 out of 4 years if P is the growth controlling nutrient. Benthic invertebrate communities are likely to be significantly more diverse than under the **Current state**, with QMCI values generally above 5, and often approaching 7. This will be due to a higher relative abundance of caddisfly larvae and mayfly nymphs. Under these scenarios, this site is expected to look similar to Photos 1d-1e during periods of low flow. However, if P is in surplus and N is the nutrient controlling periphyton growth, then I would expect only marginal reductions in maximum periphyton biomass, and only minor increases in benthic invertebrate diversity, compared with that occurring under the **Current state**.

22. **Standard Load Limit:** under this scenario the Hopelands site would be mesotrophic–eutrophic (Figure 1), displaying moderate periphyton cover of the riverbed during periods of stable flow, at any time of the year. Maximum biomass would be 30-40% less than under the **Current state** scenario and with high biomass lasting for ~ 30% less time. Based on the site hydrographs and Biggs (2000b), biomass is likely to exceed 200 mg/m^2 chlorophyll *a* for ~ 2 weeks in 3 out of 4 years under this scenario. Benthic invertebrate communities would have a moderate diversity (eg. QMCI generally above 6, and approaching 7.5 at times, and the MCI 100-120, note: the recommended water quality standard for MCI is 120 at the Hopelands site), and a moderate abundance of 'clean water' taxa.

23. **Ideal Load:** the Hopelands site would still be mesotrophic-eutrophic, displaying moderate cover of the riverbed by brown mats of diatoms, and some filamentous green algae, during periods of stable flow, with the highest biomass most commonly being in late summer and autumn. Maximum biomass is likely to be ~ 50% less than under the **Current state** and with high biomass lasting for ~ 40% less time. Re-growth following floods would be slow to moderate. Based on the hydrographs for this river, and Biggs (2000b), biomass could exceed 200 mg/m^2 chlorophyll *a* for up to 2 weeks in 3 out of 4 years. Benthic invertebrate communities would have a moderate diversity (eg. QMCI often 6.5 – 7.5 and around 8 at times; or MCI 100 – 120+), and a moderate abundance of 'clean water' taxa.

24. A stylised representation of the comparative differences in maximum periphyton biomass and resultant invertebrate communities as a function of six of the different

nutrient loading scenarios for the Manawatu River at Hopelands, discussed above, is given in Figure 2.



*for a river with mean days of accrual = 39
such as Manawatu at Hopelands

Figure 2: A *stylised* summary of the response of maximum reach-scale periphyton biomass to mean monthly concentrations of dissolved reactive P (based on P being the growth limiting nutrient), and associated benthic invertebrate communities, based on calculations for the Manawatu River at Hopelands. The outcomes of different upstream catchment management scenarios are depicted in terms of chlorophyll *a* on the chart. Key to scenarios: A = All ‘Intensification scenarios’, including ‘Current State’ – see Table 2; B = ‘Rule 13-1 Year 20 load – with no land use change’; C = ‘1/3 reduction’; D = ‘Standard load limit’ and ‘Ideal load’. The shaded area gives the approximate 95% Confidence Intervals on the predictions. QMCI categories (excellent–poor) determined from Stark and Maxted (2007).

25. I reinforce that the analysis above is a ‘case study’ and that the outcome of these scenarios in terms of in-stream environmental changes will vary amongst the different streams and rivers of the Region. In using this example to help understand the more general benefits of the POP nutrient management approach, it is my opinion that the Manawatu at Hopelands site represents a challenging situation to achieve the optimal benefits of nutrient reduction programmes, due to the relatively long periods of low flow

and stable sediments at this site; I believe greater benefits will be seen in other target zones within Horizons' Region.

Key Points: **comparison of 'Current state' with 'Rule 13-1 under no land use change'**

- In order to comment on the likely in-stream environmental outcome of implementation of the combined nutrient management approaches in the Proposed One Plan, I used a statistical model to predict the maximum periphyton biomass under several nutrient-loading scenarios (including the standard load limit) for the Manawatu at Hopelands site.
- Under the **Current state**, the Manawatu River at Hopelands is already significantly enriched (eutrophic) and due to the infrequent occurrence of high flow events that enable flushing of the river, it accrues significant periphyton biomass which will exceed the periphyton guidelines, degrade benthic invertebrate communities and be visually conspicuous.
- Under all the intensification scenarios, periphyton growth in the Manawatu River is likely to increase moderately to greatly, and reach biomass levels that are often considered to be hyper-eutrophic, aesthetically undesirable, and reduce the biodiversity of benthic invertebrate communities, with negative implications for fish, particularly trout.
- All the nutrient reduction scenarios will result in significantly lower periphyton maximum biomass and a reduced duration of high biomass events that exceed the periphyton guideline. Also, all scenarios are likely to be effective for increasing in-stream benthic invertebrate biodiversity, with the greatest gains being for adoption of the '**Ideal**' loadings.
- Adoption of any of the nutrient reduction scenarios is likely to not only prevent further increases in periphyton biomass, and associated reductions in overall in-stream biodiversity, in other target zones in the Region, but also lead to significant, and possibly greater, reductions in maximum periphyton biomass than predicted for the Manawatu River at Hopelands case study site.

Localised vs. catchment scale effects

26. I have been asked by Horizons staff to comment on the relative effects of localised vs. catchment scale effects and benefits of implementation of the nutrient control measures. Overall, I consider that the combined POP nutrient management approach would provide the most significant benefits to in-stream conditions in low order streams in small catchments, such as the tributaries of the upper Manawatu. I arrive at this

conclusion for several reasons. First, this is where the streams are most intimately linked with small scale variations in land use. This is because in these areas a significant proportion of the stream waters are usually derived directly as seepage and drains from the land vs. deeper geologically derived seepage that is most often of a higher quality. Second, catchments are generally steeper in these areas so run-off directly into the streams is more immediate (ie. lower opportunity for nutrient absorption/transformation processes on the land). Third, the steeper catchments in such areas usually result in the stream beds having coarser gravel/cobble materials which are more stable during baseflows and provide better habitat for periphyton and benthic invertebrates than finer bed materials that predominate in lower gradient areas further down the catchments. So, provisions relating to good on-farm management of effluent, controls over 'hot-spots' of nitrogen leaching, and fencing of streams in the mid and upper catchments will have the highest benefits, and these benefits will be most strongly realised locally.

27. Downstream reaches of rivers are, naturally enough, the product of the cumulative inputs of water and materials from upstream. However, whether the impacts of high nutrient inputs at upstream reaches are evident downstream is a complex interaction between biological and physical processes. In some instances, if there is limited or no additional nutrient input in mid and lower river reaches, then periphyton growth in upstream catchments can cause natural in-stream cleansing, with the result that both in-stream soluble nutrient concentrations and periphyton biomass decline in downstream reaches; these processes have been harnessed and intensified in biological reactors of wastewater treatment plants. Such downstream cleansing events have been recorded in the Manawatu River at Teachers College, where concentrations of nitrogen and phosphorus are lower than upstream concentrations at sites such as the upper Gorge and Hopelands, largely as a result of periphyton 'stripping' or attenuating nutrients in the reaches between upper Gorge and Teachers College, and from dilution from low-nutrient rivers such as the Pohangina (McArthur and Clark, 2007). However, these gains will not occur if there are significant additional nutrient inputs to the rivers (often as point-source discharges) in the mid and lower catchments. Also, in downstream reaches of many (but not all) rivers, bed sediments are not coarse enough to hold significant periphyton biomass, so high nutrients concentrations may not result in high periphyton cover in such rivers and nutrients are exported into downstream environments.

28. The degree of transferability of these predictions to other target catchments in Horizons' Region is high as periphyton has a similar and predictable response to given nutrient loadings worldwide. The main factors which will influence the local application and

transferability of the concepts are: 1) regional variations in the frequency of flood/fresh events. These will alter the mean days of accrual, with rivers having more frequent flood events being likely to have lower maximum periphyton biomasses for the given nutrient loadings (ie. achieve even greater benefits for in-stream communities) than the Manawatu at Hopelands, which has relatively long periods of stable flow; and 2) variations in bed sediment composition around the Region, whereby areas of gravel and sand/mud will have a lower periphyton biomass response to the given nutrient loadings than is expected for the Manawatu at Hopelands.

29. It needs to be recognised that during the many years of implementation of the POP, the nutrient standards will not always be met. However, major benefits will accrue in aquatic ecosystems and recreational values due to: a) reductions in maximum periphyton biomass; and b) reductions in the duration of periphyton blooms. These benefits will be amplified during long accrual periods (ie. beyond the mean days of accrual).

The trophic relationship between trout and periphyton biomass

30. I have been asked to comment on the following question: "What is the relevance of trout predation on macro invertebrate communities (particularly grazers) and hence periphyton in the Region – and specifically for rivers in the target catchments". These effects potentially occur through 'top-down' predation on some of the benthic invertebrates that graze on periphyton, with the argument that if trout remove the grazers, then the effects of nutrient enrichment on periphyton growth will be worse, so therefore trout are part of the problem. However, apart from the fact that it is unrealistic to expect to remove trout from all water bodies in Horizons' Region, to allow for more land use intensification or at least help counter the effects, this idea is too simplistic as an approach.

31. First, the potential effects of trout on periphyton biomass accrual largely depend on the nutrient loading. In systems with low-moderate loadings, trout predation can have a significant effect by reducing grazing pressure and allowing more periphyton to accrue than would be there without trout (eg., the streams where I studied the effects of trout, reported in Simon *et al*. (2004) had mean DRP concentrations of < 1mg/m^3 and mean SIN of < 10 mg/m^3, (c.f. 9-23 mg/m^3 DRP and 110-1,280 mg/m^3 SIN being considered in the POP). Further, in an earlier related study I carried out to assess 'trout effects' on periphyton production (all 6 streams were oligotrophic (Figure 1): very low nutrient levels and biomass generally < 10 mg chlorophyll *a*/m^2), I found that periphyton biomass was two-fold higher in the trout stream, but small scale nutrient enrichment resulted in a

2.6-5.7 fold increase in periphyton production in both trout **and** trout-free streams, with *the largest increases in biomass following enrichment in streams where trout were absent* (Biggs *et al*., 2000).

32. Regardless of these inconsistent results, catchments with low nutrient loadings are not the problem catchments. It is the catchments with medium to high nutrient loadings where the periphyton problems occur. In these situations it would be almost impossible to detect a 'trout effect' through trophic cascading as periphyton productivity is so high and it greatly out-strips the ability of any invertebrate grazers to exert significant control over biomass accrual, regardless of the presence of trout. In other words, over a gradient of increasing nutrients there is a 'switch point' where further addition of nutrients tips the balance in favour of the periphyton and creates an 'unbalanced' trophic cascade. Based on experience, and data from a large number of my study streams (eg. Biggs 2000b, Table 1), my opinion is that this occurs somewhere between 4 and 8 mg/m^3 DRP for P-limited streams and the quality of the invertebrate habitat will have a bearing on the exact 'switch-point'. While the presence of trout might conceivably reduce the nutrient concentration at which this 'switch-point' occurs, the reality is that it is more important to get the nutrient loading down somewhere close to this level in the first place to allow such a phenomena to occur; then invertebrate grazing will be much better placed to help in the control of periphyton production (ie. start to achieve a better 'ecological balance').

33. Interestingly, in situations of run-away periphyton production, the invertebrates usually change to being small grazers which are even less able to deal to the periphyton growth than under low nutrient loadings, and this often leads to a significant reduction in trout numbers; water quality degradation will also contribute to this loss of trout (Biggs 2000a). This means that trout are even less of a consideration under medium to high enrichment than at low loading rates. In summary, at medium-high nutrient loading rates, such as depicted under the 'Intensification scenarios' and Current state, potential trout effects are irrelevant.

34. Notwithstanding the above, I note that my periphyton biomass-nutrient model was developed based on data from streams and rivers where trout were present, so any effects are already built into the predictions and no further adjustments are required.

Response to issues raised by submitter' experts in supplementary evidence

35. Response to statements in the Supplementary Evidence of Dr Mike Scarsbrook:

i. Para. #7. The topic of the paragraph is a challenge to the lack of empirical data to link periphyton biomass to ecosystem health in the Region. Dr Scarsbrook then provides two scatter plots of chlorophyll *a* data vs. DRP and SIN to support his concern. I reject this assertion. First, the periphyton, invertebrate and fish communities of Horizons' Region have never been defined as unique. Indeed, there are no unique habitats here and these organisms don't know about regional political boundaries. Thus, there is no reason to support non-transferability of science from elsewhere in New Zealand. Second, the plots used in Figure 1 are flawed, both in terms of supporting this argument and in terms of a comparison with the model used to support the POP. The plots do not take into account flow, and they depict periphyton biomass vs. nutrients and not periphyton biomass vs. ecosystem health; these are two very different things. Further, they depict random periphyton samples and not maximum monthly biomass as used by Biggs (2000b). Thus, these data can not be realistically compared with my model and not as justification for discrediting the link between periphyton biomass and ecosystem health. As a point of confirmation of my approach, please see Figure 5 of the Evidence in Chief of Associate Professor Russell Death, which depicts local data on invertebrate MCI/QMCI declining as a function of nutrient concentrations (in this case a surrogate for periphyton biomass) and his comments in Para #39 that his analysis of local data supports my suggested nutrient thresholds.

ii. Para. #8. The topic of this paragraph is a challenge of a proposed claim during my Evidence in Chief that periphyton were 'toxic' to invertebrates and that periphyton biomass can just as easily be beneficial to invertebrates as detrimental. First, when presenting my evidence I was at pains to point out that periphyton have a number of modes of affect on invertebrates, including physical displacement. I was pointing out that only the pH effects are what could be considered 'toxic'. Second, it is incorrect to suggest that periphyton growth can just as easily have positive effects on invertebrates without any qualifiers. Yes, this does occur, but as part of a well known 'resource subsidy – environmental stress' continuum. Under this continuum, increasing periphyton production increases food availability to a certain point at the low end, which can result in higher invertebrate biomass. However, after this point (~100 mg chlorophyll *a*/m^2), further increases in periphyton become progressively detrimental to invertebrates. It is this second phase of the relationship that the POP nutrient management approach is focusing on.

iii. Para. #10. The topic of this paragraph is a challenge of the veracity of my periphyton-nutrient model, upon which many of the POP recommendations are based. For the reasons stated earlier, Dr Scarsbrook's Figure 1 does not support his suggestion, and it does not take flow into account. I do however note that the range in mean monthly nutrient concentrations exceeds the range in my dataset, particularly for SIN, which might result in the 'upper end' of the regression relationship changing a little, but not the part that is of most relevance to the POP (< 30 mg/m^3 DRP and < 300 mg/m^3 SIN). This plot also reinforces how enriched many of the water bodies in Horizons' Region are compared with what I have measured elsewhere in New Zealand. To reiterate a point I made as part of my S42A report, periphyton communities in Horizons' Region are the same as those found widely across New Zealand, and globally. Many studies elsewhere in the world have now arrived at similar conclusions to my own – for example, high periphyton biomasses that can affect ecosystem health occur at mean DRP levels > 15 mg/m^3). Nothing has been presented by Dr Scarsbrook, or any other submitter, that would place the applicability of the current model in question. The high transferability of similar relationships for lakes, except those involving phytoplankton rather than benthic algae/periphyton, is why lake eutrophication models originally developed in Canada are now used all over the world to assist with lake management.

iv. Para. #11 and #13. The topic of these paragraphs is a further critique of the general applicability of my model and the degree of uncertainty, with the implication that the uncertainty invalidates application of the model in Horizons' Region. I refer you to the above discussion. But I further add that, once again, Dr Scarsbrook has misrepresented the situation. In Figure 2 he plots spot sample data for **phytoplankton**, not periphyton. As he is an invertebrate ecologist I can understand that he might find this relationship somewhat complex and not understand why this exits, but for my algal ecologist colleagues and I such relationships are not uncommon and most are well understood. Often such relationships occur because high algal biomass (at any given point in time) tends to draw down soluble nutrient concentrations as the algae absorb the nutrients to growth. I hope that the implication isn't being made that this plot is causal as it is not; it is only correlative based on snap-shot data. Such relationships can also be found with spot sampling data in streams with periphyton – indeed, this is what can contribute to downstream water purification as noted earlier. In some streams I have recorded DRP levels below 1 mg/m^3 at times when periphyton biomass has exceeded ~ 500 mg chlorophyll *a*/m^2. Such relationships are why extensive nutrient monitoring and modeling is required, so as to estimate the average nutrient loading on the system and then the resultant maximum biomass. Of course there is some uncertainty over the specific end-point maximum biomass levels that might occur under the different scenarios for any given site and this is to be expected due to the large variety of local habitat conditions, but I assert that the direction and magnitude of reduction in periphyton biomass as a function of nutrient concentration reductions is correct and commensurate with the broader proposals to approximately halve the nutrient loadings to the streams compared with the intensification scenarios. Also, these predictions are well supported by both scientific theory and empirical results.

36. Associate Professor Russell Death also made comments about the general applicability of the periphyton model. I trust I have responded adequately above. However, I do note that in the end Associate Professor Death agrees with my suggested target guidelines, based on analysis of his local data and coming at it purely from the invertebrate perspective (his Para #39). This should give some measure of reassurance.

4. PART THREE: CORRECTIONS TO ORIGINAL S42A REPORT

37. I was suspicious of the modelled periphyton biomass results for the Manawatu at Hopelands and Mangatainoka at SH2 sites in my original S42A report because they appeared too low for the Current state nutrient concentrations, but was unable to check these properly prior to the deadline for submitting my report. After later, detailed, examination of the spreadsheet set up for me to model the scenarios, I discovered an unfortunate algebraic error. The collective effects of these corrections are that the predicted periphyton biomass values are higher, across all scenarios, than those reported in my original S42A report (ie. the periphyton biomass conditions under the **Current state** are higher than previously acknowledged). However, the *relative* changes in periphyton biomass as a function of the different nutrient management scenarios are barely affected and **my conclusions remain unchanged**.

38. I have submitted a corrected (track changes) version of my original S42A report (in particular, see Table 3). I have also included the corrected comparisons in combination with the scenarios requested of me by the Panel and Horizons staff in the paragraphs of this report. I have taken the opportunity to also add some brief points/words to clarify the text.

5. REFERENCES

Biggs, B.J.F. (2000a). New Zealand periphyton guidelines: detecting, monitoring and managing enrichment of streams. Prepared for the Ministry for the Environment by NIWA.

Biggs, B.J.F. (2000b). Eutrophication of streams and rivers: dissolved nutrient-chlorophyll relationships for benthic algae. *Journal of the North American Benthological Society* 19: 17-31.

Biggs, B.J.F.; Francoeur, S.N.; Huryn, A.D.; Young, R.; Arbuckle, C.J.; Townsend, C.R. (2000). Trophic cascades in streams: effects of nutrient enrichment on autotrophic and consumer benthic communities under two different fish predation regimes. *Canadian Journal of Fisheries and Aquatic Sciences* 57: 1380-1394.

Clothier, B.; Mackay, A.; Carran, A.; Gray, R.; Parfitt, R.; Francis, G.; Manning, M.; Duerer, M.; Green, S. (2007). Farm Strategies for Contaminant Management. A report by SLURI, the Sustainable Land Use Research Initiative, for Horizons Regional Council.

McArthur, K.; Clark, M. (2007). Nitrogen and phosphorus loads to rivers in the Manawatu-Wanganui Region: An analysis of low flow state. Technical report to support policy development. Report no. 2007/EXT/793, Horizons Regional Council.

Parfitt, R., Dymon, J.; Ausseil, A.; Clothier, B.; Deurer, M.; Gillingham, A.; Gray, R.; Houlbrooke, D.; Mackay, A.; McDowell, R. (2007). Best practice phosphorus losses from agricultural land. Landcare Research Report LC0708/012.

Simon, K.S.; Townsend, C.R.; Biggs, B.J.F.; Bowden, W.B.; Frew, R.D. (2004). Habitat-specific nitrogen dynamics in New Zealand streams containing native or invasive fish. Ecosystems 7: 1 – 16.

Stark, J.D. (1998). SQMCI: a biotic index for freshwater macroinvertebrate coded abundance data. New Zealand Journal of Marine and Freshwater Research 32:55-66.

Stark, J.D.; Maxted, J.R. (2004). Macroinvertebrate community indices for Auckland's soft-bottomed streams and applications to SOE reporting. Prepared for Auckland Regional Council. Cawthron Report No.970. Cawthron Institute, Nelson. ARC Technical Publication 303.59 p.

Stark, J.D.; Maxted, J.R. (2007). A User Guide for the Macroinvertebrate Community Index. Prepared for the Ministry for the Environment. Cawthron Report No.1166. 58 p.