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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SECTION 42A REPORT OF DR BARRY JOHN FRANKLYN BIGGS ON BEHALF OF HORIZONS REGIONAL COUNCIL

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1. INTRODUCTION

My qualifications/experience

1. I have the following qualifications: BSc (Hons) degree from Victoria University of Wellington majoring in Botany and Geology, and a PhD from the University of Canterbury, Christchurch, majoring in Zoology (stream ecology). I am a member of the NZ Limnological Society and the North American Benthological Society.

2. Since July 2008, I have been employed as the General Manager of NIWA Operations, based in Christchurch. Prior to this I was Chief Scientist responsible for NIWA Environmental Information and International science programmes and from 2002 to 2006, I was employed as Regional Manager of NIWA Christchurch. Earlier positions with NIWA were as Principal Scientist in Stream Ecology and Ecohydrology, Christchurch, and as a research scientist with DSIR and the Ministry of Works and Development (commencing 1977). I have published more than 100 peer reviewed papers and contributed to more than 100 client reports. I was also a principal contributor to the Ministry for the Environment (MfE) Environmental Flow Guidelines and wrote the MfE NZ Periphyton Guideline (Biggs 2000a); I have also led many large-scale, multi-disciplinary, science programmes investigating water allocation and land use issues (eg. Project Aqua in the Waitaki River). I have served as a member of the Executive of the North American Benthological Society (the main professional body representing freshwater scientists in North America) and served as an Associate Editor of the Journal of the North American Benthological Society (the preeminent international journal for the science of river ecology). In 1999 I was award a Royal Society NZ Science & Technology Silver Medal for achievements in freshwater ecology and ecohydrology.

3. I confirm that I have read the Environment Court's practice note Expert Witnesses – Code of Conduct and agree to comply with it. This evidence is within my area of expertise, except where I state that I am relying on what I have been told by another person. I have not omitted to consider material facts known to me that might alter or detract from the opinions that I express.

My role in the One Plan

4. I have provided input to the development of the Horizons' Proposed One Plan through early discussions with staff on a values-based approach, input to the technical group on limiting nutrients for controlling undesirable periphyton growth (Wilcock et al. 2007) and as a technical reviewer of reports that fed into the Plan's water quality aspects on values

(Ausseil & Clark, 2007a). I also assisted with developing a regional periphyton and water quality monitoring programme that will eventually be used to verify the benefits of the One Plan nutrient reduction strategies.

Scope of evidence

5. My evidence will be on (i) the overall approach of the Proposed One Plan for identifying values, defining water quality standards and management of nutrient enrichment; (ii) the current state of water quality in the Manawatu-Wanganui Region, as indicated by nitrogen and phosphorus concentrations; (iii) the importance of setting water quality standards, with an emphasis on nitrogen, phosphorus and periphyton standards; (iv) the likely environmental outcomes of implementation of the FARM strategy for managing non-point source nutrient enrichment; (v) the adequacy of the methods proposed in the technical report entitled A Framework for Managing Non-point Source and Point Source Nutrient Contributions to Water Quality (Roygard & McArthur, 2008); (vi) whether discharges from hydroelectricity dams should be subject to water quality standards; (vii) consideration of the recommendations in the Council Officer’s report to the Hearing Panel of Kate McArthur relating to nutrient standards.

2. EXECUTIVE SUMMARY OF EVIDENCE

6. In my evidence I discuss nutrient enrichment and periphyton proliferations caused by nutrient enrichment and I consider the approaches in the Proposed One Plan (POP) intended to manage nutrient enrichment associated with intensive agriculture, and consequently, manage the occurrence of periphyton proliferations. To provide background to the material on these issues, I explain nutrient-periphyton relationships and the development of the nutrient standards and nutrient-based periphyton standards, distinguish between effects-based and reference site-based standards, and comment on likely responses of periphyton to variation in nutrient standards and flow levels. I also review current water quality monitoring results in Horizons’ Region, as they concern dissolved nutrients. One of the most important messages to convey in this portion of the evidence is that periphyton-nutrient relationships cannot be viewed independently of river flow regimes. In the agricultural landscapes that dominate Horizons’ region (and which are of primary concern for the POP), periphyton biomass is jointly controlled by flow conditions (particularly the magnitude and frequency of floods) and nutrient availability (particularly dissolved inorganic nitrogen and phosphorus).

7. The POP uses a sequence of steps to link desirable management outcomes in freshwater ecosystems to land use practices in the Region. The steps in this sequence

that pertain to my evidence are: 1) the establishment of concentration-based nutrient standards intended to prevent periphyton biomass from exceeding threshold values; 2) quantitative relationships between nutrient loading from land and nutrient concentrations in streams, and 3) land-based nutrient management that is intended to reduce nutrient loading. Periphyton biomass is one of the environmental indicators used in the POP for two reasons. First, periphyton proliferations are a primary symptom of excessive nutrient input to streams. Second, these proliferations have deleterious effects on ecological, cultural and socio-economic values. As a consequence, the nutrient standards in the POP are largely based on the potential stimulation of nuisance periphyton growth by dissolved inorganic nitrogen and phosphorus. The major values identified in the POP as vulnerable to periphyton proliferations are life-supporting capacity, contact recreation, trout fisheries and trout spawning habitat.

8. I support the general approach used to link management outcomes in water bodies to land use practices because it is objective and underpinned by extensive science. However, we all need to recognise that there is qualitative and quantitative uncertainty in this multi-step approach which raises the risk that compliance with nutrient loading limits and numerical standards in some circumstances might not achieve the management objectives.

9. The threshold values for maximum periphyton biomass (ie. the periphyton standards) in the POP are 50 mg chlorophyll *a* /m^2 for upland areas with currently low nutrient levels and high potential for benthic biodiversity; 120 mg/m^2 for hill countries areas with moderate nutrient levels that are currently agriculturally productive and potentially high trout fishery values; and 200 mg/m^2 for lowland areas, naturally P-enriched catchments, and soft-sediment geology. The sliding scale reflects both the range of values and realistic expectations of the standards that can be achieved. In intensively-farmed lowland areas, periphyton biomass may reach relatively high levels even under conditions of best agricultural practices. A pragmatic approach is to treat the six steps listed above as opportunities for adaptive management, ie. use results from and feedback about water quality management under the POP to adjust one or more components of the Plan.

10. As noted in Paragraph 6, the nutrient concentrations that correspond to periphyton biomass depend on the flood regime. One of the best hydrological predictors of maximum periphyton biomass is the mean accrual period (the time between bed-moving floods, when high biomass can develop). Maximum periphyton biomass can be predicted from statistical models that relate dissolved inorganic nitrogen and phosphorus

concentrations, and accrual periods, to biomass. These statistical models are in the New Zealand Periphyton Guideline (Biggs, 2000a). The nutrient standards assigned by the POP to each subcatchment in Horizons' Region are based on mean accrual times over a year, and the mean monthly nutrient concentrations (based on at least one year of monthly sampling) predicted to result in periphyton biomass below the standards listed in Paragraph 9.

11. The concentration-base nutrient standards in the POP are converted to instream nutrient inputs from land (loadings) through a process developed by Roygard and McArthur (2008). The specific loading rate that corresponds to a nominated nutrient standard is then termed the 'standard load limit'. Instream loads are defined as the products of flow rate and concentration. However, standard load limits cannot be accurately determined by simply replacing observed nutrient concentrations with nutrient standards. There are several intervening steps, including: 1) removing the effects of flood flows (when concentration standards do not apply); 2) estimating nutrient concentrations between sampling times; 3) complex flow-concentration relationships, accounting for different land use capability (LUC) classes; and 4) separating the contributions of point-source and non-point source inputs to instream loads. Again, this is a complicated process and there is uncertainty associated with each step, but it is logical, transparent and objective. The recommended nutrient standards in the POP apply only at flows above the 20th flow percentile for a site, as nutrient supplies during flood flows are likely to be offset by high levels of periphyton removal by abrasion and scouring.

12. The Proposed One Plan requires landowners who practice intensive agriculture in priority water management zones to prepare a Farmer Applied Resource Management (FARM) strategy to meet the conditions of their resource consent. In order to comment on the likely environmental outcome of the FARM strategy, I used a statistical model to predict the maximum periphyton biomass under several nutrient-loading scenarios (including the standard load limit) for two sites (Biggs, 2000b). The model predictions indicate that a shift in SIN and DRP loads from the current state to the standard load limits would be accompanied by 30-75% reductions in maximum monthly periphyton biomass.

3. EVIDENCE

Recap of overall approach of the Proposed One Plan

13. Horizons proposes a systematic approach to water quality management, consisting of six steps: 1) identification of values of aquatic ecosystems (eg. inanga spawning) that are affected by activities associated with water (eg. discharge of sediment from bridge construction); 2) classification of the Region into water management zones based on factors such as land use, hydrologic regime, resource pressure, water quality monitoring results and catchment geology (eg. Lower Manawatu zone); 3) development of management objectives that must be met to maintain or improve the values within the zones (eg. the water body supports healthy life / aquatic ecosystems); 4) definition of numerical standards to be met to achieve the management objectives (eg. annual average soluble inorganic nitrogen concentration ≤ 444 mg/m^3 when river flow is $\leq 3\times$ median); 5) development of quantitative relationships between nutrient input (loading) from point and non-point sources and water quality state; 6) regulation of agricultural nutrient management, as detailed in the FARM (Farmer Applied Resource Management) strategy (FARM Strategy Workbook, 2007). This sequence of steps can be seen in Chapter 6 and Schedule D of the Proposed One Plan (POP). I support the general approach that has been proposed because it is objective and based on extensive scientific knowledge of how stream ecosystem health is affected by land use development/water quality degradation and flow regimes. The links between water quality condition and values are tractable, as is the identification of streams and rivers where values are at risk due to poor water quality.

14. Each of the steps listed above has associated with it assumptions and uncertainty. The assumptions include that many water bodies are the same ecologically if they have the same landscape settings (as defined by the water management zones), and transferability of quantitative relationships between water bodies is thus appropriate. Sources of quantitative uncertainty include measurement error, incomplete models, and natural variability. The cumulative effects of uncertainty in the POP water quality approach raise the risk that compliance with nutrient loading limits and numerical standards will not achieve the management objectives. There is always uncertainty in predictions of environmental effects of land use and land use management. However, we need to use the best science to inform decisions, but allow for subsequent ‘fine-tuning’ if all issues and responses haven’t been adequately allowed for in the predictions or assessments. Indeed, it is important that there is opportunity for adaptive management (ie. use results from and feedback about water quality management under the POP to adjust one or more components of the Plan). Tests of the effectiveness of

best-management practices (BMP) for agriculture and forestry provide some precedence for this approach. Like the POP water quality management approach, BMPs are often implemented in a series of steps, and have multiple objectives. Consequently, tests of BMP effectiveness generally take a weight-of-evidence approach, in which separate criteria are used to evaluate the achievement of each objective, and overall effectiveness is based on collective achievement of objectives (i.e, management objectives are outcome oriented).

15. The technical documents supporting Horizons' proposal for water quality management refer to "translating" values into water quality standards (Ausseil and Clark, 2007b). However, it is important to note that this "translation" does not simply match values and standards; specific standards vary among water management zones and subzones according to the predominant values that are present. Within zones and subzones, further variation in water quality standards has been proposed in response to variation in the risk of degradation, variation in natural nutrient enrichment, and variations in the hydrology and configurations of streams. A key element degrading the waterways is the proliferation of attached algae and microbes (periphyton); the risk of this decreases with decreasing accrual periods, and is lower in soft-bottom streams than in cobble-bedded streams. Therefore, some streams with high degradation risk have more stringent standards than others with low degradation risk. Some water management zones and subzones are naturally nutrient-enriched (due in part to phosphorous-rich geology, atmospheric nutrient deposition and plant-derived soil nitrogen). Proposed nutrient standards for some of these zones are less stringent than for those lacking natural enrichment. Finally, at tributary confluences, the water quality standards of the downstream tributary apply.

Numerical standards

16. The proposal to base water quality management and improvement on numerical standards is a relatively new direction for New Zealand regional councils (with the exception of microbial water quality). Guidance from central government recommends a shift in regional natural resources plans from narrative or qualitative criteria to numeric standards. The proposed National Policy Statement for Freshwater includes a requirement that regional councils include numeric water quality standards in regional plans (MfE, 2008). The potential benefits and problems of numeric standards are considered in greater detail in Section 5 below. In general, numeric water quality standards provide an unequivocal baseline for measuring progress towards

management objectives, and an objective basis for identifying sites that comply or do not comply with water quality requirements.

17. As noted above, numeric standards are most relevant when they are developed for, and applied to, specific classes of water bodies or geographic zones within shared climatic, hydrological and geological areas. When multiple classes or zones are combined (eg. by pooling water bodies across catchments or regions), the resulting standards may be overly stringent for some sites, and overly permissive for others. On the other hand, it is not practical or cost efficient to develop or apply numeric standards to individual water bodies. These points are reiterated in Dr Quinn's evidence statement. Appropriate classes or zones for numeric standards may be identified on the basis of a hierarchical classification system such as the River Environment Classification (REC), or on the basis of geographic proximity. The latter approach presumes that sites in close proximity (eg. in the same river catchment) have common climatic, hydrological, and geological conditions. However, this assumption is often not met. Thus, the numeric standards in the POP are based on the New Zealand REC, with some modifications in the geology and source-of-flow levels of the hierarchy which will better reflect regional conditions. The specific modifications and the rationale are discussed in a HRC technical report (Ausseil and Clark, 2007c). The numeric standards in the POP are specific to each water management zone (see POP Schedule D, Tables D.16 and D.20).

Background to periphyton, nutrient-periphyton relationships, and the development of the nutrient-based periphyton standards

18. The water quality standards in the POP include two classes of dissolved inorganic nutrients: dissolved reactive phosphorus (DRP) and soluble inorganic nitrogen (SIN). Periphyton is the primary link between nutrient standards and stream and river values in the POP. More generally, periphyton proliferation is a primary symptom of excessive nutrient input to streams and rivers. The combination of increased nutrient input and periphyton proliferation are referred to in this evidence as eutrophication. In this section, I provide background information on the environmental effects of eutrophication, periphyton-nutrient relationships, and the development of nutrient-based periphyton standards.

19. Benthic algae, cyanobacteria and associated micro-organisms (periphyton) occur on the bed of most streams and rivers, and rarely pose an environmental problem. Indeed, periphyton is a fundamental component of aquatic ecosystems as it influences nutrient cycling, provides food and habitat for invertebrates, and may comprise a substantial

proportion of aquatic biodiversity. Periphytic organisms are predominately photoautotrophs – like plants, they use sunlight and dissolved inorganic carbon (eg. carbon dioxide) to produce carbohydrates/biomass.

20. As with all organisms, periphyton require multiple nutrients for growth, maintenance of their metabolism and for reproduction. These nutrients include nitrogen (N), phosphorus (P), potassium, calcium, silicon and iron. Most research, and management efforts concerned with periphyton and nutrients, focus on N and P because the availability of these nutrients is often the limiting factor for periphyton growth. While N and P are often present in streams at high concentrations compared with other nutrients, the demand for N and P by organisms is also quite high. Therefore, N and P may be scarce relative to demand, and periphyton growth ceases when demand exceeds availability. Periphyton acquire most of the N and P they require in a dissolved inorganic form. Inorganic nutrients lack the hydrocarbon structures that are present in all organic compounds and thus are easier to absorb and metabolise. The most common inorganic forms of N are nitrate (NO_3^-) and ammoniacal N (NH_4^+), both of which can be assimilated by periphyton. On average, NO_3^- concentrations are about four times higher than NH_4^+ concentrations at the stream and river monitoring sites in the Manawatu-Wanganui Region. The most common inorganic forms of P are various phosphates (eg. orthophosphate, pyrophosphate, metaphosphate); only orthophosphate (PO_4^{3-}) can be assimilated by periphyton. In water quality monitoring datasets, concentrations of NO_3^- and NH_4^+ are often summed (as they are both absorbed by periphyton) and the combined soluble inorganic N (SIN) concentrations reported. Dissolved reactive P (DRP) is usually used as an indicator of PO_4^{3-} concentrations. The absolute concentrations of SIN and DRP, and their relative concentrations (indicated by the SIN:DRP ratio) are very widely used as a general indication of the risk of excessive periphyton growth (discussed below).

21. One of the most common responses to increases in N and P in streams/rivers from intensive land use is accelerated periphyton growth and accumulations of thick, slimy mats. In cases where nutrient-enhanced periphyton growth exceeds the rate of removal by invertebrate herbivores, floods and desiccation (during extreme low flows), periphyton biomass can increase to “nuisance” levels. Nuisance refers to ecologically, economically and/or aesthetically deleterious effects of accumulations of periphyton. Nutrient enrichment can also cause changes in periphyton composition, and may favour toxic algal species over benign species. There are many potentially deleterious effects of periphyton proliferations and changes in composition. Some of the most common effects are listed here:

a. Benthic habitat degradation and loss of aquatic diversity (particularly for invertebrates), declines in populations, and impairment of reproduction.

b. Production of toxins or irritants and subsequent deleterious effects on contact recreation, livestock, potable water supplies.

c. Impairment of angling.

d. Increasing day/night fluctuations in stream water dissolved oxygen and pH, reduction of dissolved oxygen due to periphyton decomposition, and subsequent deleterious effects on aquatic animals and nutrient cycling.

e. Reduction of visual aesthetic values and creation of odour problems.

f. Clogged irrigation and industrial water supply intakes.

g. Financial costs for control and management of periphyton, lost revenue by recreational, agricultural and industrial interests.

22. In addition to periphyton proliferations, dissolved nutrient enrichment may lead to several other ecological and human health risks. In slow-flowing rivers and estuarine river reaches that receive tidal water, phytoplankton may be abundant and may undergo rapid growth (“blooms”) under nutrient-enriched conditions. Direct negative effects of dissolved N on human and stock health, including methaemoglobinemia (oxidation of haemoglobin iron), are rare and mainly occur through high nitrite exposure and ammonia toxicity. Nitrite in natural waters is rapidly oxidised to nitrate, so doesn’t pose a widespread health risk. Un-ionized ammonia is toxic or elicits avoidance in invertebrates and fish at concentrations between about 0.5 and 8.5 mg/L; as with nitrite, elevated ammonia concentrations are typically associated with point source inputs of effluent, manure, not unpolluted river water. So, given the relatively high risk of periphyton proliferations in response to moderate nutrient enrichment, and the relatively low risk of direct negative effects on humans and livestock, it is most appropriate to chose periphyton as the primary value on which to base stream nutrient standards.

23. The guidelines used for assessing and managing periphyton by most regional and unitary authorities in New Zealand are contained in the New Zealand Periphyton Guideline (Biggs 2000a). This document recommends levels of periphyton biomass (as cover of the stream bed and biomass) intended to prevent degradation of benthic biodiversity, angling, and aesthetic values. The recommendations were derived from empirical relationships between periphyton biomass and benthic invertebrate diversity and dissolved oxygen concentrations, and a review of public preferences for aesthetic conditions.

24. The most important factors influencing periphyton biomass are the frequency of high stream flows (freshes or floods) or dry periods (= ‘hydrological disturbances’), and the availability of nutrients (DRP and SIN) and light. The degree of disturbance of periphyton during such events is a function of flow magnitude, substrate size and mobility. Severe hydrological disturbances (floods or droughts) reduce periphyton biomass through drag-induced sloughing, sediment abrasion, rock tumbling, and desiccation. Therefore, periphyton biomass generally increases with time since being disturbed (ie. the “accrual period”). During these periods, nutrient availability strongly influences the rates at which periphyton grows and expands across streambeds. Nutrient availability and disturbance frequency have compensatory effects such that higher nutrient concentrations mean that periphyton will grow faster and reach proliferation levels in shorter time. Thus, under such conditions undesirable growth can occur even if a stream has quite frequent disturbance events. However, if nutrient concentrations are low, then very long periods without disturbance events are required before high biomass accrues. In this latter situation, there is much greater opportunity for a rain/high flow event to occur to remove the growing mats, so the occurrence of such proliferations in these streams is rarer. Thus, the nutrient concentration which will lead to proliferations has been adjusted in the Guidelines to reflect the hydrological regime (and expected/‘normal’ accrual period of any given river). The three variables of concern (accrual period and DRP and SIN concentrations) are plotted in a nomograph to predicted maximum periphyton biomass during any given year. By knowing the approximate accrual period at a site (which can be estimated using hydrological records), threshold DRP and SIN concentrations, the likelihood of proliferations/trophic state can also be estimated.

25. The nomograph used in the periphyton guideline does not predict periphyton biomass *per se*, because statistical relationships between periphyton biomass and accrual period and DRP and SIN concentrations leave a substantial amount of the variation in periphyton biomass unexplained. Instead, the nomograph identifies threshold biomass levels separating eutrophic, mesotrophic and oligotrophic streams. Eutrophic streams (maximum periphyton biomass > 200 mg chlorophyll *a* /m^2) have conspicuous periphyton, which is dominated by large filamentous green algae at sites with long accrual periods. Under these conditions, invertebrate and fish biodiversity is generally low, and the streams may be unsuitable for contact recreation or angling. Mesotrophic streams (maxima between 60 and 200 mg chlorophyll *a* /m^2) are moderately enriched. In mesotrophic streams with long accrual periods, periphyton may also be dominated by filamentous algae, which can moderately reduce biodiversity and recreation values.

Oligotrophic streams (maxima < 60 mg chlorophyll *a* /m^2) tend to have inconspicuous periphyton dominated by diatom films, high biodiversity and high recreation values.

26. The photosynthetic algae and bacteria that dominate periphyton communities require sunlight. Periphyton biomass is generally low in heavily-shaded streams, and nutrient enrichment rarely stimulates rapid growth in these streams. Thus, light limitation of growth over-rides nutrient limitation in such streams and offers some options for mitigating effects of nutrient loading through riparian retirement and tree-planting (Rutherford *et al.,* 1999). The same riparian buffers may also reduce nutrient input to streams from developed agricultural land. Riparian retirement/planting requires long-term landowner commitment, which often results in piecemeal plantings along catchments. This reduces effectiveness as extensive areas on both sides of the channel are required to achieve detectable benefits to water quality and on periphyton. More generally, while there is considerable conceptual support for the role of riparian buffers in mitigating effects of intensive land use, there is less empirical support (Parkyn *et al.,* 2003). Consequently, riparian retirement or planting should not be viewed as an alternative to on-farm nutrient management, but as a supplementary component.

Key Points

- I support the approach taken by Horizons Regional Council to define concentration-based nutrient standards for protecting instream values. Numerical standards conform to national stream enrichment guidelines while providing an objective basis for measuring progress towards management objectives, and for assessing water quality at monitoring sites.
- Periphyton proliferation is the primary symptom of excessive nutrient input to streams, and the nutrient standards in the POP are largely based on the potential stimulation of nuisance periphyton growth by dissolved inorganic nitrogen and phosphorus.
- In addition to nutrient supplies, hydrological disturbances regulate periphyton proliferation. Therefore, nutrient standards for individual catchments or subcatchments need to account for the frequency of hydrological disturbances.
- The POP contains nutrient standards for water management subzones (ie. subcatchments); these standards are based on estimates of the frequency of hydrological disturbances, and the nutrient concentrations required to stimulate periphyton proliferations. The New Zealand Periphyton Guideline and expert opinion was used to produce the standards.

Current state and trends in dissolved nutrients in streams of Horizons' Region

27. Several Region-wide water quality assessments have been made in Horizons Region; these assessments differ in number of monitoring sites, duration of sampling and distribution of sites. Two recent reports on water quality state and trends are the Horizons water quality standards report (Ausseil and Clark, 2007) and a technical report on water quality trends (Gibbard *et al.,* 2006). In the following text, I summarise the results of those reports for DRP and SIN.

28. Table 22 in Ausseil and Clark (2007) contains annual mean, and summer mean, DRP and SIN concentrations for sites in the various subzones. The sites are an amalgam of NIWA National River Water Quality Network (NRWQN) sites and Horizons' State of the Environment (SOE) monitoring sites. Some water management subzones lack any monitoring, so coverage of the 117 sub-zones in the Region is incomplete (reflecting constraints in resourcing and priority for areas with high pressures). Annual average DRP concentrations for the period January 1997-January 2007 range from 5-900 mg/m^3, and SIN concentrations from 11-2200 mg/m^3. Table 27 of the Ausseil and Clark (2007b) report has a more detailed comparison of annual average state versus the proposed standards for each water management subzone. Four categories are used in the assessment: highly compliant with standard (concentration < 90% of standard), marginally compliant (concentration between 90 and 100% of standard), highly non-compliant (concentration > 110% of standard), and marginally non-compliant (concentration between 100 and 110% of standard). The comparison indicated that for SIN, 53 subzones were highly non-compliant, two were marginally non-compliant, and 15 were highly compliant. For DRP, 38 subzones were highly non-compliant, four were marginally non-compliant, three were marginally compliant, and 23 were highly compliant.

29. Gibbard *et al.* (2006) assessed trends in DRP and NO_3^- at 22 Horizons' monitoring sites in the Rangitikei, Manawatu, Whanganui and Whangaehu catchments. The trend analyses used flow-corrected nutrient data. Flow correction is a procedure used to remove the variation in water quality data attributable to variation in stream flow which, unless done, can bias results due to variable dilution, channel and bank sediment flushing, indirect effects on biotic retention, run-off from various land uses and other mechanisms. Significant trends of increasing DRP concentrations were detected at seven sites, and significant trends of increasing NO_3^- concentrations were detected at six sites. No negative trends in DRP concentrations were detected, and only one negative trend in NO_3^- was detected.

30. Scarsbrook *et al.* (2006) assessed trends in total P, total N, DRP, NO_3^-, and NH_4^+ for the period 1989 to 2003 at the seven NRWQN sites that NIWA operates in Horizons' Region (two each on the Whanganui and Rangitikei Rivers and three on the Manawatu River). Trends of increasing DRP were detected in each river; NO_3^- increased in the Manawatu and Rangitikei Rivers; NH_4^+ increased at one site in each of the Manawatu and Rangitikei Rivers; and total N increased at two sites on the Manawatu River. A summary of additional water quality trend analyses carried out in the Region is given in Kate McArthur's evidence statement on water quality. The most relevant of these are two reports that include trend analyses for NRWQN and SOE monitoring sites in the Region for the period 2001-2008 (Ballantine and Davies-Colley, 2009a, 2009b). These trends are relevant for the POP because they may indicate the effects of more recent land use changes in the Region. This analysis revealed negative trends in SIN at nine sites (6 SOE sites, three NRWQN sites), and negative trends in DRP at three NRWQN sites. While these results are interesting, it should be noted that no statistically significant trends were detectable at most sites. The most parsimonious interpretation of the trend analyses is that current poor water quality at many sites is due to environmental degradation (most likely land use changes) before the 2001-2008 period.

31. In addition to the preceding analyses, I calculated median concentrations of SIN and DRP for each of 12 sites in Horizons' long-term SOE monitoring network, for the period January 2000 to January 2008. Median SIN concentrations at eight sites exceeded the recommended POP standards, and median DRP concentrations exceeded the recommended standards at three sites.

32. Collectively, the above observations suggest that water quality degradation is probably quite common in streams and rivers of the Region. Nitrate concentrations are particularly high in the upper Manawatu, Mangatainoka, Makuri, Waikawa, Lake Horowhenua and Tutaenui catchments, and DRP concentrations are particularly high in the Manawatu catchment, in Tutaenui, Porewa and Rangitawa Streams (tributaries of the Rangitikei River), and Waikawa Stream.

33. The water management zone framework in the POP is commendable in that it addresses three key needs: 1) assessment of water quality conditions over time; 2) compliance with standards; and 3) increased spatial resolution, which should improve Horizons' ability to draw inferences about water quality at region, district and catchment scales. To meet these objectives, Horizons may have to expand or reconfigure its SOE monitoring network, as many of the water management subzones currently lack monitoring sites (Ausseil and Clark, 2007b).

34. It should also be noted that the proposed concentration standards for DRP range from 6 to 15 mg/m^3, and the detection limit for DRP at the analytical laboratory employed by Horizons is 5 mg/m^3. This is a relatively high detection limit; analytical laboratories in New Zealand routinely achieve detection limits of ≤1 mg/m^3. The measurement precision at the detection limit is 33%, so values reported as 5 mg/m^3 range from 3.8 to 6.7 mg/m^3. The small difference between detection (5 mg/m^3) and exceedance of the 6 mg/m^3 standard at some sites, together with the relatively low precision, suggest that there will be some false exceedances. That is, some samples that are close to the detection limit will be incorrectly scored as exceeding the standard.

Key Points

- Analyses of various water quality datasets suggest that many streams and rivers in Horizons' Region suffer from inorganic nutrient enrichment and that many parts of streams and rivers will not comply with the standards in the POP.
- Few statistically significant trends were detected in analyses of recent (2001-2008) nutrient concentrations. This could suggest that long-term degradation has stabilised.
- There are relatively few water quality monitoring sites in the Region relative to the high physical heterogeneity, and no water quality data are available for many of the proposed water management subzones.
- To meet the monitoring objectives in the POP, Horizons needs to expand and/or reconfigure its SOE monitoring network.

The Importance of setting water quality standards

35. The basis for most water quality assessments undertaken in New Zealand are the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC, 2000). The ANZECC guidelines consist of "trigger" values for water quality parameters that are intended to be compared with median values in a water body. If trigger values are not met (either exceeded or too low), a management response is recommended. The ANZECC guidelines for New Zealand were derived from water quality data from the NRWQN. For nutrient guidelines, 80th percentile values were computed for relatively unimpacted upland and lowland sites in the network. After removing lake-fed and glacier-fed sites, there are 18 unimpacted upland sites and three unimpacted lowland sites. While the ANZECC guidelines are not highly representative of the full range of unimpacted streams and rivers in New Zealand, they do serve as a useful guide.

36. The proposed water quality standards in the POP differ in intent and authority from the ANZECC guidelines. In general, guidelines do not have any statutory standing and they generally offer several levels of environmental protection, which are provided as 'options' that may apply to different types of water bodies or different management purposes.

Reference-based standards versus effects-based standards

37. The proposed SIN and DRP standards are effects-based standards, with some modifications. Effect-based standards are derived from quantitative causal relationships. Derivation of these standards is a two-step process. First, quantitative relationships are developed between response variables (usually environmental or social values such as periphyton biomass, trout abundance or natural character) and the presumed causal variables (eg. nutrient concentrations or loading rates). Second, thresholds are identified in the relationships, beyond which the response variable is considered impaired. These thresholds correspond to levels in the causal variables that are used as numeric standards or trigger values. Many of the river assessment tools in common use in New Zealand were developed using this processes, including habitat suitability curves, the Macroinvertebrate Community Index (MCI) and the periphyton guideline. The use of effects-based guidelines conforms with the RMA, which requires effects-based criteria to determine whether particular activities are detrimental to particular ecosystems.

38. It is important to distinguish between effects-based standards and reference-based standards. The ANZECC trigger values described above for nutrients are reference-based, as they correspond to 80th percentile values from nutrient datasets, without regard for environmental effects of nutrients. Both effects-based and reference-based standards have underlying assumptions. When using reference-based guidelines, it is assumed that the reference sites are truly unimpacted or minimally impacted, that the reference sites are appropriate for comparison with impacted sites (ie. they differ only in the degree of human impact), and that the reference-based standards correspond to desirable outcomes. When using effects-based standards, it is assumed that the causal relationships used to derive the standard are transferable between sites, that the causal variables tightly control the activity of concern, that the causal variables are, in-turn, controlled by the higher-level human activity being managed (eg. that nutrient loading represents agricultural intensification), and that the response variables are appropriate for the management objectives. To clarify this last point, the development and use of effects-based standards requires the selection of environmental and/or social values on which to base assessments and desired outcomes. These values correspond to the

response variables discussed above. There are a very large number of potential values provided by rivers, and it is crucial to identify values that accurately represent objectives and outcomes desired by the community. For more information about the selection of values used in the POP, please see the technical report on values (Ausseil and Clark, 2007), and schedule D of the POP, which links 23 individual values to the water management subzones (Table D1).

Periphyton and nutrient standards in the POP

39. As noted above, the most important controls on periphyton biomass are hydrological disturbances, nutrient supply and light levels. Of these factors, nutrient supplies and riparian shade are strongly influenced by land use, and are therefore frequent subjects of regional council management and planning. Maintenance or creation of vegetated riparian buffers can shade narrow stream channels and reduce periphyton proliferations. Riparian buffers are the subject of several best-practice initiatives in New Zealand. The primary controlling factor that is associated with catchment-scale land use is nutrient supply, and controlling periphyton proliferations through improved nutrient management is the aim of the nutrient standards in the POP. Increases in the severity and frequency of periphyton proliferations in response to increases in nutrient supplies have been documented world-wide, and reductions in periphyton proliferations following reductions in nutrient supplies have also been documented (eg. Biggs, 1989). Therefore, using nutrient standards to control nutrient supplies and consequently, periphyton growth is a logical approach. The following sections cover the specific periphyton and nutrient standards in the POP.

40. In the technical report on water quality standards for the POP, it is noted that periphyton standards are needed to protect four major values: life-supporting capacity, contact recreation, trout fishery, and trout spawning (Ausseil & Clark 2007b). Periphyton cover and biomass standards are given in Schedule D of the POP (Tables D.17 and D.20). Periphyton biomass standards in the POP are given as areal chlorophyll *a* densities (ie. mg chlorophyll *a* /m^2). Chlorophyll *a* is one of the pigments in algae and photosynthetic cyanobacteria that absorb light energy required for photosynthesis and subsequent growth. The mass of pigment is often used in lieu of the total mass of periphyton, because periphyton communities often contain large numbers of invertebrates and protozoans, and large quantities of particulate organic matter and inorganic sediment which would bias estimates of biomass. The specific chlorophyll *a* pigment is used, because all algae and cyanobacteria contain this pigment. It should be noted that chlorophyll *a* concentrations vary among periphyton taxa and vary in response to light

level. These differences cause some of the variability that characterises chlorophyll-nutrient relationships derived from natural streams.

41. Three standards are specified in the POP for periphyton biomass: 1) maximum of 50 mg chlorophyll *a* /m^2 for upland areas with generally low nutrient levels and high potential for benthic biodiversity; 2) maximum of 120 mg/m^2 for hill countries areas with moderate nutrient levels and potentially high trout fishery values; and 3) a maximum of 200 mg/m^2 for lowland areas, naturally P-enriched catchments and soft-sediment geology in the catchment. The sliding scale reflects both the range of values and realistic expectations of the standards that can be achieved. In intensively-farmed lowland areas, periphyton biomass may reach relatively high levels even under conditions of best agricultural practices. The periphyton cover standard is 30%, consisting of filamentous algae and in all water management subzones; this value comes directly from the New Zealand Periphyton Guidelines (Biggs, 2000a); it corresponds to a cover level that is conspicuous to recreational river users and may interfere with angling.

42. I recommend the additional periphyton cover standard of no more than 60% cover by diatoms/cyanobacteria more than 0.3 cm thick, as stated in the New Zealand Periphyton Guideline (Biggs, 2000a), is added to the periphyton cover standard in the POP.

43. The POP sets out concentration-based standards for DRP and SIN (Schedule D, Tables D.16 and D.20) required to achieve these periphyton biomass standards. To comply with those standards, dischargers of nutrient-laden waste to water and land owners will have to comply with standard load limits, discussed below. In this section, I review the concentration-based standards. As noted previously, the DRP and SIN standards are specific to each water management subzone. The load standards represent best efforts to translate permissible levels of periphyton that meet the standards in each sub-zone, into nutrient concentrations.

44. The recommended nutrient standards in Schedule D apply only at flows above the 20th flow percentile for a site, as higher nutrient supplies during flood flows are likely to be offset by high levels of periphyton removal by abrasion and scouring at such times. The recommended nutrient standards for rivers draining lakes apply at all river flows, as these rivers are expected to have dampened flood regimes.

45. A small number of streams flowing from forested headwater catchments exceed the nutrient concentrations standards in the POP (Ausseil and Clark, 2007b Table 27). To allow for these circumstances, I recommend a proviso be added to the nutrient

standards that sets the standard as either: 1) the numerical value for the water management sub-zone as set out in table D.17, or 2) the naturally occurring nutrient concentration in streams flowing from forested headwaters, which ever is the greater of the two. This will ensure that streams with naturally elevated nutrient concentrations, with no potential for land use related enrichment, are not considered to be 'non-complying' with the standards in the POP.

The timing, frequency and duration of nuisance periphyton blooms in relation to different nutrient standards and flow percentiles

46. As noted above, flow regimes (particularly at times of bed-moving floods), light and nutrient supplies are the primary controllers of periphyton biomass accrual. Extensive sampling at 30 sites in 25 streams/rivers across New Zealand (Biggs, 2000b) has demonstrated that where there is little or no light limitation:

    a. Low average nutrient concentrations generally result in low average periphyton biomass, regardless of accrual time. While peak biomasses > ~ 50 mg Chla/m^2 do occur occasionally in such systems, they are of short duration (~ few weeks) and do not appear to damage invertebrate and fish communities;

    b. Low to moderate average nutrient concentrations can result in moderate to high peak periphyton biomass (ie. > 120 mg Chl a/m^2) if accrual periods are long (eg. > 100 days), but usually not if accrual periods are substantially shorter as in streams/rivers draining mountain areas. With such nutrient concentrations, periods of high biomass can persist for several months (providing flows are stable) and result in modest changes to invertebrate and fish communities. Further, the maximum biomass generally correlates with nutrient supply concentrations, so that higher nutrient concentrations result in higher mean and maximum biomass (ie. thicker and more extensive beds of algae) until light limitation of the underlying layers starts occurring (through 'self-shading'). Also, proliferation conditions persist for much longer (ie. a higher proportion of the year) in these streams/rivers;

    c. In streams/rivers with very frequent flood disturbances, proliferations of periphyton are generally not possible even with high nutrient concentrations (because of flushing effects) unless there is an unusually dry period.

47. As the time required to accrue high biomass increases, it will take longer to attain peak biomass and thus such conditions will occur later in the growing season. However, the timing of proliferations is less likely to be influenced by nutrient regimes than by the seasonal characteristics of the flow regimes. Strong seasonal patterns in periphyton

biomass appear to be limited to streams with stable flow regimes (eg. spring-fed streams). At these sites, growth peaks often occur in late winter/early spring, and in autumn (Biggs, 2000a). Reductions in nutrient supply or in accrual periods may cause delays in these peaks. Late-season periphyton proliferations are likely to be attenuated more frequently by autumn floods, which will reduce the overall duration of such proliferations.

48. It is important to consider changes in flood regimes that may co-occur with changes in nutrient management. As can be deduced from the above, for a given flow regime, increasingly rigorous standards should lead to fewer, shorter and later periphyton proliferations. However, future surface water allocation systems may increase the use of flood harvesting for off-channel storage, thereby reducing the frequency and /or magnitude of small-moderate size floods downstream of intakes. Damping flood regimes can potentially increase accrual periods, which could offset gains associated with rigorous nutrient standards.

49. The 20th flow percentile is used as the nutrient standard “cut-off” in the POP with higher flows (0-20th percentile) being exempt. Increasing the flow percentile at which nutrient standards apply would increase the risk of periphyton accumulations in two ways. First, the higher the percentile cut-off, the longer the proportion of each year that is exempt from nutrient standards. Second, the higher the percentile cut-off, the more small-moderate sized floods are exempt and some of these freshes may be effective at suppressing periphyton biomass accrual.

50. The 20th flow percentile recommended in the POP is relatively permissive. Hydrological analyses indicate that the ≤ 20th percentile flow band includes the 3× median flow threshold (used as a general statistic to determine average days available for periphyton accrual, discussed earlier) at 49% of 63 flow monitoring sites in the Region. This means that the nutrient standard does not apply at some flows below the 3× median threshold at approximately 50% of sites. The 3× median threshold is not exact (ie. it does not correspond to the minimum flow for periphyton removal at every site). However, precaution suggests that expanding the band of exempt flows that are < 3× median from the current recommendation would be overly permissive. I recommend maintaining the 20th flow percentile cut-off.

Key Points

- The nutrient concentration standards in the POP (Schedule D) represent best practice to translate permissible levels of periphyton in each sub-zone, into nutrient concentrations; the key controller of periphyton biomass accrual that can be managed.
- Permissible maximum periphyton biomass levels in the POP are 50 mg chlorophyll *a* /m^2 for upland areas with generally naturally low nutrient levels and high potential for benthic biodiversity; 120 mg/m^2 for hill countries areas with moderate nutrient levels and potentially high trout fishery values; and 200 mg/m^2 for lowland areas, naturally P-enriched catchments, soft-sediment geology, and often with poor physical habitat for instream biota. The sliding scale reflects both the range of values and realistic expectations that can be achieved from the standards.
- I recommend the additional periphyton cover standard of no more than 60% cover by diatoms / cyanobacteria more than 0.3 cm thick is added to the standards in the POP.
- The recommended nutrient standards in Schedule D apply only at flows above the 20th flow percentile for a site, as nutrient supplies during flood flows are likely to be offset by high levels of periphyton removal by abrasion and scouring.
- A proviso should be included in Schedule D to provide for naturally elevated nutrient concentrations in streams flowing from forested headwater catchments, to ensure that these are not considered to be non-complying with the standards of the POP.

Development of nutrient standards in the water quality standards report

51. The POP provides nutrient standards for each water management sub-zone, as summarised in Table D.17 of Schedule D, (see also Table 22 of Ausseil and Clark (2007)). Here, I summarise the procedure used to develop those nutrient standards. Four types of information relating to nutrient levels and risks of periphyton proliferations were considered: 1) model predictions of nutrient concentrations that cause periphyton proliferations (from the New Zealand Periphyton Guideline (Biggs, 2000a)); 2) my professional opinion (primarily concerning nutrient standards for subzones in which the model did not apply); 3) observed mean monthly concentrations in summer (1st October – 31st April); and 4) year-round mean concentrations. Concentration data were not available for every subzone.

52. The New Zealand Periphyton Guideline model was used to develop nutrient standards for the various subzones, based on the nominated periphyton biomass standards for these zones. This model uses the average interval between freshes or floods > 3 x the median flow (calculated from flow records) to estimate the 'expected' time available for periphyton biomass to accumulate in any given river. This accrual period (mean days of accrual; MDA) and mean monthly nutrient concentrations, are then used as predictor variables for biomass. However, there are some limitations with the application of this model in Horizons' Region. First, some areas of the Region have hydrological conditions that do not fit the calibration dataset for the model (in particular, the Central Plateau). Second, the current model does not account for effects of invertebrate herbivores or abrasion by suspended sediment on periphyton biomass. Third, the periphyton biomass data currently held by Horizons is insufficient for testing the calibration of the model for the Region. My professional opinion was used to fill some gaps associated with these limitations.

53. In applying the above procedure, two general modifications were made. First, a Region-wide rule was applied that downstream standards take precedence over the upstream standards. If a tributary had a higher allowable standard than the mainstem it fed, the standard for the tributary was adjusted to match that of the mainstem. This is intended to prevent degradation of high-quality, high-order streams. Second, my recommended standards for either SIN or DRP were relaxed at some sites where there was a clear indication that one nutrient was likely to be more frequently limiting periphyton growth, and there was a large gap between the recommended standard and the observed concentration of the presumed non-limiting nutrient.

Nutrient loads, and point and non-point nutrient sources

54. To remain in compliance with nutrient concentration standards, it is likely that many (if not all) point and non-point sources of nutrients will need to be curbed in some way in a number of the subzones. Point sources can be controlled at daily or shorter intervals, but non-point sources will need to be controlled at longer intervals due to longer generation and transport times. Also, it needs to be recognised that many of the procedures used to reduce nutrient losses from land (and input to water bodies) require long periods to become effective and for detectable benefits to be observed (eg. because of the time needed for riparian vegetation enhancement). Tools for nutrient management and budgeting typically work at annual time steps and it is proposed that limits be set on annual nutrient losses from various land uses, which would then work towards achieving long-term compliance with the concentration–based standards

discussed above. The processes proposed to determine those limits are discussed in the following section.

Adequacy of the methods proposed in the technical report entitled "a framework for managing non-point source and point source nutrient contributions to water quality" (Roygard and McArthur, 2008)

55. Roygard and McArthur (2008) developed a methodology for converting concentration-based nutrient standards to 'standard load limits'. A standard load limit is calculated from the nutrient standard and flow record. Instream loads are defined as the products of flow rate x concentration. However, standard load limits cannot be accurately determined by simply replacing actual nutrient concentrations with nutrient standards. There are several intervening steps, including: 1) removing the effects of flood flows (when concentration standards do not apply); 2) estimating nutrient concentrations between sampling times; 3) complex flow-concentration relationships; 4) accounting for different land use capability (LUC) classes; and 5) separating the contributions of point source and non-point source inputs to instream loads. This last step is important because instream loads represent the net effects of multiple inputs, generally from multiple landowners. Roygard and McArthur (2008) produced several alternative methods by which the SIN and DRP load limits for multiple flow levels (flow decile categories) can be established. Variation among methods gives the appearance of a highly complex process and, in fact, the process of establishing flow-specific, LUC-specific, water management zone specific loads is complicated. The variability in flow and nutrient data quantity and quality increases the challenge. But the framework is logical and the individual steps in the process are clear.

Key Points

- Standard load limits refer to annual nutrient inputs from various land uses that are expected to result in permissible instream nutrient concentrations.
- Standard load limits for each water management subzone were calculated from the products of the nutrient standards (concentrations) and volumetric flow, corrected for high flows. Standard load limits were used to develop nitrogen loss limits from intensive land uses prepared for multiple land use capability classes.

Likely environmental outcomes of implementation of the FARM Strategy

56. To reiterate some key points of the POP, as context for my evaluation of instream outcomes: Rule 13-1 of the POP requires land owners who practice intensive agriculture in priority water management zones to prepare a Farmer Applied Resource Management (FARM) strategy to meet the conditions of their resource consent for undertaking a controlled land use activity.

57. The POP applies the concentration-based nutrient standards discussed above to the FARM strategy as follows. Section 13-2 of the POP sets out the target water management zones where intensive farming land use activities will be controlled, the dates by which the Rule 13-1 provisions come into force and also the nitrogen leaching/run-off values by Land Use Capability (LUC) class that will need to be met by land owners over the next 20 years. Rule 13-1 requires land owners to use the FARM strategy as the mechanism for complying with the nitrogen leaching/run-off values determined in Table 13.2 of the POP, and thereby complying with their resource consent for intensive land use in a target catchment, by the specified dates and working towards reducing nutrient loads in the river towards the standard load limits.

Periphyton responses to changes in nutrient loading

58. In order to test the likely instream outcome of implementation of the FARM strategy, several nutrient-loading scenarios were considered for two sites, the upper Manawatu River at Hopelands and the Mangatainoka River at SH2. In each scenario, the response variable (ie. the environmental outcome) was estimated periphyton biomass. As noted previously, increased periphyton biomass is a primary consequence of high nutrient loading.

59. The nutrient loading scenarios considered in the analysis, and the corresponding annual loads for nitrogen and phosphorus for each site, are listed in Tables 1 and 2. Definitions of the scenarios are as follows:
    a. **Current state** – measured annual load from Roygard and McArthur, 2008.
    b. **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 and McArthur (2008) for point source reductions. This model assumes no change in land use or intensity.

c. **'Standard' load limit** – annual load calculated from POP standards for SIN ($0.444\ g/m^3$) and DRP ($0.01\ g/m^3$) using methods in Roygard and McArthur (2008).

d. **Ideal load** – annual load calculated from my recommended nutrient standards (see Table 22 of Ausseil and Clark, 2007 standards report) for SIN ($110\ g/m^3$) and DRP ($0.01\ g/m^3$) using methods in Roygard and McArthur (2008).

e. **Rule 13-1 Year 1 load** – annual load calculated by Clothier *et al.* (2007) using N loss limits proposed in the Rule 13-1 Year 1 requirements. This model assumes full intensification of all suitable LUC class land in the catchment (class 3 or better).

f. **Rule 13-1 Year 5 load** – annual load calculated by Clothier *et al.* (2007) using N loss limits proposed in the Rule 13-1 Year 5 requirements. This model assumes full intensification of the catchment up to the N Loss limits specified in Table 13.1

g. **Rule 13-1 Year 10 load** – annual load calculated by Clothier *et al.* (2007) using N loss limits proposed in the Rule 13-1 Year 10 requirements. This model assumes full intensification of the catchment up to the N Loss limits specified in Table 13.1

h. **Rule 13-1 Year 20 load** – annual load calculated by Clothier *et al.* (2007) using N loss limits proposed in the Rule 13-1 Year 20 requirements. This model assumes full intensification of the catchment up to the N Loss limits specified in Table 13.1.

i. **1200 kg MS/ha load** – annual load calculated by Clothier *et al.* (2007) using N loss limits predicted from intensification of current dairying land average production (1000 kg MS/ha) to higher average production (1200 kg MS/ha).

j. **Sheep and beef intensification** – annual load calculated by Clothier *et al.* (2007) using N losses predicted from intensification of sheep and beef stocking rate to 12.2 su/ha on current sheep and beef land use cover (does not account for intensification of any other land use).

k. **LUC expansion load** – 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 (average production 1000 kg MS/ha).

Table 1. Nutrient load scenarios for the upper Manawatu River at Hopelands

Scenario	**N load tonnes / year**	**P load tonnes / year**
Current state	745.1	21
1/3 reduction	490.1	12
Standard load limit	358	8.1
Ideal load	89	8.1
Rule 13-1 Year 1 load	863.1[1]	-
Rule 13-1 Year 5 load	828.1	-
Rule 13-1 Year 10 load	777.1	-
Rule 13-1 Year 20 load	755.1	-
1200 kg MS/ha	991	-
Sheep and beef intensification	807.7	-
LUC dairy expansion	877.7	-

Table 2. Nutrient load scenarios for the Mangatainoka River at SH2

Scenario	**N load tonnes / year**	**P load tonnes / year**
Current state	602.8	9.3
1/3 reduction	401.1	5.9
Standard load limit	266.3	6.0
Ideal load	66	6.0
Rule 13-1 Year 1 load	361.5	-
Rule 13-1 Year 5 load	335.5	-
Rule 13-1 Year 10 load	312.5	-
Rule 13-1 Year 20 load	302.5	-

60. The nutrient load scenarios were used to estimate periphyton biomass in five steps:

i. The proportion of the annual SIN and DRP load that currently occurs in each flow decile at each site was taken from the Framework Report discussed above (Roygard and McArthur, 2008). These proportions correspond to the first scenario 1 in Tables 1 and 2, “Current state”.

ii. The annual load for each flow decile in each alternative scenario in Tables 1 and 2 was calculated on the basis of the same proportions as those calculated for the current state.

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[1] Note: although nutrient reduction strategies are proposed, the overall load still increases as a result of allowing for intensification of all LUC Class 3 or better land in the upper Manawatu (worst case scenario approach).

iii. Average daily loads (g N or P/day) and average instantaneous loads (g/sec) were calculated by dividing the annual loads for each flow decile in each scenario by 365 days, then by 86,400 sec/day.

iv. Average instantaneous concentrations (g/m^3) were calculated by dividing the instantaneous loads for the midpoint flow in each decile class (ie. 5th, 15th, 25th, 35th etc…).

v. Periphyton biomass was estimated for the average SIN and DRP concentration in the 30th-100th flow decile classes, for each site and scenario, given the instantaneous concentrations calculated in steps 1-4. The estimates were made using the regression equations in Biggs (2000b). These equations were developed to predict maximum monthly periphyton biomass from mean monthly SIN or DRP concentrations, and from mean days of accrual. There are separate equations for SIN and DRP; both calculations were made here. Differences in the predicted outcome of the two equations are related to the form of nutrient limitation at a site; the SIN-based equation is likely to be more accurate at nitrogen-limited sites, and the DRP-based equation is likely to be more accurate at phosphorus-limited sites. Estimates of mean days of accrual for the Manawatu at Hopelands (36 days) and the Mangatainoka at SH2 (22 days) were from Henderson and Diettrich (2008).

61. The estimates of periphyton biomass required several assumptions. First, there is substantial variation in concentration within each flow decile under current conditions. This variation reflects natural and human-caused variability in flow-concentration relationships. The same variability affects all estimates of annual loads, but separating loads into flow deciles has the effect of reducing this variability somewhat. Second, it was assumed that the proportion of the nutrient load per flow decile remains the same as in the current state, regardless of nutrient management scenario. In the absence of information about changes in flow-loading relationships, this was the most parsimonious approach.

Results of periphyton biomass predictions

62. Under current conditions, periphyton biomass in the Manawatu River at Hopelands is predicted to range from ~ 90 to 200 mg chlorophyll *a* /m^2, and in the Mangatainoka River at SH2, from ~ 20 to 70 mg chlorophyll *a* /m^2 (Table 3). Based on these predictions, the Manawatu River at Hopelands is mesotrophic-eutrophic, and the Mangatainoka River at SH2 is oligotrophic-mesotrophic, according to the New Zealand Periphyton Guideline classification. High nutrient concentrations at both sites indicate that periphyton biomass

would be considerably greater if the accrual periods were longer (eg. during a dry year with few floods). The generally lower biomass levels in the Mangatainoka River reflect the shorter mean accrual period.

63. If the standard load limits were achieved, periphyton biomass is predicted to decrease by 30-75% in the Manawatu River at Hopelands, and by 30-67% in the Mangatainoka River at SH2 (Table 3). Assuming periphyton growth is nitrogen-limited, the "ideal load" scenario from the Ausseil and Clark (2007) standards report would lead to ~ 65% reductions in periphyton biomass at both sites.

Table 3. Predicted instantaneous SIN and DRP concentrations and periphyton biomass for the Manawatu at Hopelands and the Mangatainoka at SH2, under different nutrient loading scenarios. MDA: mean days of accrual. Nutrient concentrations are 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}

	River							
	Manawatu River at Hopelands (MDA: 36 d)				**Mangatainoka River at SH2 (MDA: 22 d)**			
Scenario	**SIN**	**DRP**	**Chl (N)**	**Chl (P)**	**SIN**	**DRP**	**Chl (N)**	**Chl (P)**
Current state	870	23	205	89	1210	12	73	18
1/3 reduction	580	13	167	25	910	9	64	6
Standard load limit	430	9	144	21	600	9	52	6
Ideal load	110		72		150		26	
Rule 13-1 Year 1 load	1030		224		820		60	
Rule 13-1 Year 5 load	980		218		760		58	
Rule 13-1 Year 10 load	920		211		710		56	
Rule 13-1 Year 20 load	900		209		690		54	
1200 kg MS/ha load	1180		240					
Sheep and beef	960		216					
LUC dairy expansion	1040		225					

Key Points

- In order to comment on the likely environmental outcome of implementation of the FARM strategy, I used a statistical model to predict the maximum periphyton biomass under several nutrient-loading scenarios (including the standard load limit) for two sites.
- The model predictions indicate that a shift in SIN and DRP loads from the current state to the standard load limits would be accompanied by 30-75% reductions in maximum periphyton biomass for any month of the year.

Should discharges from hydroelectricity dams be subject to water quality standards?

64. Horizons posed the question to me: Should discharges from hydroelectricity dams be subject to water quality standards? To answer this question, I considered three general classes of discharges from hydro dams.

A. Operating or residual flows

Yes, water quality standards should apply at all but flood flow levels. As noted in the technical reports on nutrient standards (Ausseil and Clark, 2007; Roygard and McArthur, 2008), these standards should apply at all flows that are below the flow cut-off of 20% level of the flow distribution. Some river water released from hydroelectric power stations, impoundments, canals and tunnels result from inter-basin transfers. While the SIN and DRP in these releases are sourced from other catchments, they have identical biological effects as SIN and DRP source from the recipient catchment. Therefore, inter-basin transfers should not be exempt from nutrient standards in the POP.

B. Flushing flows and/or channel maintenance flows required by operating consents

No, water quality standards should not apply for two reasons. First, these flows are likely to be above the flow cut-off. Second, the longer-term environmental benefits of these short-term events are likely to outweigh the detrimental effects of short periods of elevated nutrient concentrations.

C. Natural floods that are passed over or around dams

No, water quality standards should not apply for the same reasons given in B, above.

Key Points

- Concentration-based nutrient standards should apply at all operating and residual flows released from hydro dams, with the exception of flood flows above the cut-off applied to other streams and rivers.
- Flushing flows, channel maintenance flows and natural floods with magnitudes above the flow cut-off should be exempt from the nutrient standards. The benefits of these short-term events are likely to outweigh the effects of periods of elevated nutrient concentrations.

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