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 JOHN MARTIN QUINN

ON BEHALF OF HORIZONS REGIONAL COUNCIL

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1. INTRODUCTION

My qualifications/experience

1. My tertiary qualifications are a BSc (Hons) (First Class, Zoology major) from the University of Otago and a PhD from Massey University, where I wrote a thesis on the effects of wastewater discharges around Palmerston North on sewage fungus and water quality in the Manawatu River.

2. My early professional experience involved 18 months as an advisor to the National Water and Soil Conservation Authority's Water Resources Council.

3. For the last 24 years I have worked for NIWA and its predecessors as a research and consulting scientist. My main focus has been on the ecology of rivers in relation to the effects of a variety of human activities, including wastewater discharges, forestry and agricultural land use and riparian management. I have been involved in the National Rivers Water Quality Network since its establishment in 1989. I was an instigator of the Whatawhata Sustainable Land Management Project in 1996 and continue to research the effects of changes, implemented in 2001, in land use and management of this hill-land farm on stream water quality and ecology.

4. I have led development of conceptual and predictive models of the links between land management practices and waterway values in each of the five Dairy Best Practice Catchments.

5. I have managed long-term studies on the effects of forest management practices on Coromandel Peninsula streams since 1993.

6. I have led NIWA research programmes on River Ecosystems and Land Use Interactions and currently lead NIWA's Restoration of Aquatic Ecosystems programme.

7. I have published more than 80 scientific papers in peer-reviewed journals or books and have written over 115 consulting reports. Among these are reports advising on water use class standards in the Resource Management Act and the Manawatu Catchment Water Quality Regional Plan in 1993 (McBride and Quinn 1993). I wrote the Ministry for the Environment's (1992) Water Quality Guideline No 1 on control of undesirable biological growths in rivers. In 2003 I was awarded a Royal Society of New Zealand Science and Technology Bronze Medal for my contributions to river ecosystems research.

8. I have read the Environment Court's practice note 'Expert Witnesses – Code of Conduct' and agree to comply with it.

My role in the One Plan

9. 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), standards (Ausseil & Clark, 2007b), the early draft of the Water Quality Framework report (Roygard & McArthur, 2008) and the Farm Strategies for Contaminant Management report (Clothier et al., 2007).

Scope of evidence

10. My evidence will be on (i) the overall approach of the Proposed One Plan to identifying values, defining water quality standards and management of nutrient enrichment; (ii) the importance of identifying water body values in the Plan; (iii) the importance of setting water quality standards for aquatic ecosystem health and life-supporting capacity and standards for deposited bed sediment and contact recreation; and (iv) the need for improvements in water quality in the Horizons Region.

2. EXECUTIVE SUMMARY OF EVIDENCE

11. I support the overall approach of the Proposed One Plan to water quality management, of identifying the community's key values for water bodies and defining and monitoring water quality standards to protect these values within a Water Management Zones (WMZs) framework. I contend that this is consistent with the effects-based philosophy of the Resource Management Act (1991).

12. Setting standards involves trade-offs between simplicity/practicality for ease of application and efficiency (ie. not over- or under-protecting the environmental values). I support the Proposed One Plan's (POP) use of "shall not exceed" standards (without percentiles specified) for attributes that have potentially lethal effects on biota, such as maximum temperature, minimum dissolved oxygen and ammonia. However, some attributes (eg. BOD_5 and visual clarity) should be assessed at averages over defined timescales, reflecting the way these have been used to define effects on riverine values.

13. The temperature standards in the POP specify daily maxima and levels of change not to be exceeded, but do not define the measurement regime or whether the change is measured relative to the status quo or the temperature regime expected under natural shading conditions. I recommend that change should be measured as the difference in annual mean temperature and annual summer maximum temperature relative to the natural reference condition.

14. I contend that the BOD standards in the POP are unnecessarily stringent and are not well focused. I recommend aiming these standards towards prevention of sewage fungus development by changing the <1 and <2 g total BOD_5/m^3 standards in various WMZs to *averages* of 1.5 and 2 g soluble carbonaceous BOD_5/m^3, respectively. I also recommend applying these standards at flows below the 20^{th} percentile, with the averages applying at weekly or greater scales (ie. not hourly or a daily average) to reflect the timescales of BOD impact on sewage fungus. BOD is an expensive parameter to measure and is only really useful where point source pollution is significant. Hence I recommend restricting its routine application for monitoring to WMZs which have point source organic pollution issues.

15. The particulate organic material (POM) standards in the POP are <2.5 or < 5 g/m^3 at all river flows for different WMZs, and aim to prevent degradation of the stream bed habitat from excessive deposition of particulate organics in order to protect macroinvertebrate communities. I recommend including the 5 g/m^3 POM standard, applied as an average under low flow conditions (< median flow) at all riverine WMZs, as a practicable method of controlling the organic particle load in rivers.

16. Periphyton cover is a useful biological indicator of both ecosystem health and suitability of streams for recreation. Data for six Horizons' Region sites in the National River Water Quality Network over 1990 to 2006 indicate that: (i) average annual maximum cover by filamentous algae exceeded the MFE guideline of 30% at three sites: Whanganui River at Te Maire, and Manawatu River at Weber Rd (upper catchment) and Opiki (downstream of Palmerston North). Filamentous algae cover was increasing in the Whanganui River at Te Maire and the Rangitikei River at Kakariki, whereas there was a weak declining trend at Manawatu River at Weber Road. Although these results cover a small number of sites, they indicate that there are sites within the Horizons Region where periphyton cover degrades aesthetic conditions.

17. Benthic macroinvertebrates provide robust indicators of stream and river condition. I recommend use of the Macroinvertebrate Community Index (MCI), rather than the

Quantitative MCI (QMCI) for general State of the Environment (SOE) monitoring, but using the QMCI for monitoring the effects of point source discharges. I recommend substituting the Schedule D QMCI standards in Table D.17 of 5 and 6 with MCI standards of 100 and 120 respectively.

18. The timescales for recovery of biota once habitat quality has been restored (eg. water quality standards are met) are expected to vary in relation to the life cycles of species and the connectivity between the restored habitat and sources of the sensitive biota that have been lost. The restoration of suitable habitat can be delayed considerably after establishing restoration measures due to time required for riparian forest regrowth and lags in the system response to mitigations/restoration due ongoing input of contaminants stored in soils (eg. Cadmium, DDT), groundwaters (eg. nitrate) and streambanks (eg. sediment). Small streams recover shading most quickly and natural thermal regimes and MCI levels can be expected within 6-10 years of riparian replanting along 2-4 m wide streams.

3. EVIDENCE

19. **Overall approach of the Proposed One Plan:** I support the overall approach of the Proposed One Plan to water quality management, of identifying the community's key values for water bodies and defining water quality standards to protect these values within a catchment classification scheme. This approach is consistent with the effects-based philosophy of the Resource Management Act (1991). My experience in working with a range of groups has been that stakeholders are more likely to engage with environmental management when they identify with the target values (eg. safe swimming, healthy fisheries, clear water) and can see the linkages between their activities and the water quality targets (or standards) designed to protect these values.

20. **Use of water quality standards versus narrative guidelines:** I support the way that the water quality standards are applied within the frameworks of water management zones (WMZs) and life supporting capacity (LSC) classes in the Proposed One Plan. Where appropriate, numeric water quality standards are helpful for management to protect water values because they provide specific targets for point and diffuse source contaminant management. These can be varied with experience, in an adaptive management approach, if monitoring of the standards and values they aim to protect indicates this is necessary.

21. An example of use of quantitative standards in adaptive management was the use of an in-river BOD_5 standard of <5 g m^{-3} in the Lower Manawatu River "cleanup" during the

1980s to control the growth of sewage fungus and associated dissolved oxygen depletion due to wastewater inputs from Palmerston North City and the milk and meat processing plants at Longburn. This standard was based on studies in the United Kingdom related primarily to BOD_5 from treated sewage discharges. It provided an initial target for wastewater treatment, but my research and monitoring showed that the effluent from the milk processing plant had a greater effect on sewage fungus per unit of BOD_5 added than sewage-derived BOD_5. This was due to the milk processing wastewater containing proportionately more low molecular weight organics that bacteria can take up readily. Hence a lower target (increase <2 g BOD_5 m^{-3}) was needed when this effluent comprised about 50% of the river BOD_5 (Quinn & McFarlane 1988). Adopting this lower target helped solve the severe pollution problems in the Lower Manawatu River at that time (Quinn & Gilliland 1989).

22. Water quality standards are particularly useful when designed for a specific context at local (eg. sub-catchment – catchment or river class) scales. In contrast, standards are often inappropriate at regional and national scales because they do not allow for the natural differences in water bodies due to factors like catchment geology, natural geothermal inputs, stream shading, flow regimes and streambed type (which influence periphyton response to nutrient concentrations as outlined in Dr Biggs evidence): ie. for many aspects of water quality one size does not fit all. Hence, at regional and national scales, narrative standards supported by guidelines are often most appropriate to guide protection of values without detailing numeric standards that are likely to be both inefficient and ineffective.

23. The Water Management Zones (WMZs) used in the Proposed One Plan (POP) provide a framework for effective application of numeric water quality standards, by applying these at a scale at which they can be tailored to the water body characteristics and key values. The WMZs are based on the River Environment Classification (REC), which is widely accepted as a core water resource and conservation planning tool in New Zealand, with some modification of the geology layers underlying the LSC value (see Ausseil & Clark 2007 REC report). The WMZs provide a practicable framework for monitoring compliance with standards and maintenance of waterway values that will provide a basis for refining standards by adaptive management to optimise effectiveness and efficiency.

24. **Comparing the POP approach with international trends in water management:** The POP plan approach to managing point and diffuse source contaminant loads to meet water quality criteria that will sustain key values has similarities with the Watershed Total

Maximum Daily Load (TMDL) process used in the United States to manage contaminant loads to waters that are defined as “impaired” because they do not meet water quality standards under the Clean Water Act. A TMDL specifies the maximum amount of a pollutant that a water body can receive while still meeting water quality standards, and allocates pollutant loadings among point and non-point pollutant sources. A TMDL is the sum of the individual wasteload allocations (WLAs) for point sources and load allocations (LAs) for non-point sources and natural background (40 CFR 130.2), with a margin of safety. The process of calculating and documenting a TMDL typically involves a number of tasks, including characterising the impaired water body and its watershed, identifying sources, setting targets, calculating the loading capacity using some analysis to link loading to water quality, identifying source allocations, preparing TMDL reports, and coordinating with stakeholders. Between 1995 and 2008, more than 34,300 approved TMDLs were developed by individual US states or established by the US Environmental Protection Agency (EPA); these TDMLs addressed more than 36,000 listed impairments.

25. The POP approach also has similarities to the European Water Framework Directive, which requires European Union member states to develop "river basin management plans" to achieve general protection of the aquatic ecology in all waters and specific protection of unique and valuable habitats, protection of drinking water resources, and protection of bathing water at selected sites. Thus the general form of the POP process is well established internationally.

26. **Importance of specific physico-chemical water quality standards:** In the following sections I will explain the importance of several of the water quality variables that are set as standards in the POP to protect waterway values. It is important to be aware that typically rivers are exposed to multiple stressors that often interact, adding to complexity of prediction of impacts and biota recovery. For example, pH affects the proportion of total ammonia that is present as toxic unionised ammonia versus ammonium ions. The effects of nutrients on periphyton biomass are particularly complex, being influenced by lighting at the stream bed, water temperature, stream bed stability, current velocity, invertebrate grazing pressure and the time between scouring flows. Setting standards involves trade-offs between simplicity/practicality for ease of application and efficiency (ie. not over-protecting or under-protecting the environmental values).

27. **Expressing standards as “shall not exceed” limits:** The standards in the POP (Tables D.16 & D.17) are set as single defined maxima or ranges (eg. temperature <19 °C and change from natural ≤3 °C in Management Zone Mana_1). Hamill (2008)

argues against this approach and that these standards would be better expressed as averages for some attributes (eg. BOD and turbidity) and percentiles for others (eg. for temperature upper limit this might be 90^{th} percentile <19 °C) to reflect the information from which the some of the standards were derived. I agree with Hamill that some attributes (eg. BOD_5 and visual clarity) should be assessed at averages over defined timescales, but support the POP approach of using maximum values (without percentiles specified) for attributes that have potential lethal effects on biota, such as maximum temperature, minimum dissolved oxygen and ammonia.

28. These maximum ("shall not exceed") standards are targets for Horizons management and any minor breaches that occur will be interpreted as such, and will not result in prosecutions (as exceedence on discharge consent limits may). Ausseil and Clark (2007b, p. 139) discuss the level of compliance expected for such attributes and recommend use of the 95 percentile of data collected at the site for interpreting compliance, ie. a site would be taken as meeting the standard if 95% of data collected are less than the stated maximum for the water management zone. I support this approach of having simple maximum standards in the One Plan, with advice on interpretation in the supporting document, because assessing percentile compliance is not straightforward. For example, different 95%ile results will be obtained depending on whether data are collected as monthly spot measurements or at more frequent intervals (eg. 30 minute intervals) using data loggers. Results also depend on the assessment timescale (annual, seasonal, or daily), and the most appropriate timescale for assessment will vary between attributes. I discuss this issue further below in relation to individual attributes.

29. **Temperature:** Water temperature is a key control of aquatic ecosystem characteristics and function through its strong influence on the rates of biogeochemical processes (eg. respiration, photosynthesis), physical processes (eg. gas exchange at the water surface and dissolved oxygen (DO) saturation) and biota growth rates. All biota have optimum temperature ranges and maximum tolerances. For example, stonefly and mayfly larvae are more sensitive to high temperature than caddisfly, while beetle larvae and koaro are more sensitive than eels (see Table 7 in Ausseil and Clark 2007). Hence, changing the temperature regime can alter: (i) community composition, (ii) the outcome of biological interactions (eg. control of periphyton growth by grazing invertebrates), and (iii) eliminate sensitive species, if tolerance thresholds are exceeded.

30. **Temperature regimes:** These vary at diurnal and annual scales, driven mainly by solar heating. The amplitude of diurnal variation tends to be greatest in small-medium sized

streams without shade during late summer (Quinn & Wright-Stow 2008). Heat is transported downstream so that temperature management requires an integrated catchment management approach. If shallow headwater streams are shaded, they transport cool water to the deeper rivers that have more resistance to solar heating due to their depth; this reduces temperature increases throughout the catchment. The main human influences on water temperature are: alteration of shade by riparian vegetation and channel widening, which increases the canopy gap over the channel; and reduction of stream depth due to abstraction and discharge of cooling water/geothermal fluids. Global climate change may also impact on temperatures in the longer term.

31. The rationale for the temperature standards in the POP (Table D.16) is set out in the report of Ausseil and Clark (2007b). These provide temperature standards for protecting life supporting capacity (LSC) that vary between LSC classes (ie. from 2° C change and 19° C maximum in UHS (Upland Hard Sedimentary) and UVA (Upland Volcanic Acidic) classes to 3° C and 23° C in LM (Lowland Mixed).) Trout Fishery (TF) waters have a temperature change limit of 3 °C and daily maximum temperature standards of 19 °C in Class I (Outstanding) and Class II (Regionally significant) waters and 24 °C in Class III (Other significant fisheries) waters. Having limits on both the degree of change from the natural situation and the maximum allowed level is warranted to protect natural thermal regimes, as well as protecting aquatic life from thermal stress.

32. The ≤ 2° C or 3° C change standard in the POP is relatively simple to apply to point discharges of cooling waters (after mixing) or before and after logging of riparian vegetation. However, it is difficult to interpret in relation to general rural land use because of the complexities involved in defining the "natural" temperature maximum against which change should be measured at a point in a catchment. It is unclear whether this refers to the current state or that expected with natural riparian vegetation cover. I would recommend the latter as the benchmark for assessing change, to avoid interpreting a temperature reduction of >3 °C due to restoration of riparian shade as a breach of the standard, when this is obviously beneficial to instream values.

33. The temperature change standards do not define the timescale of measurement that also influences their interpretation. For "diffuse" land use effects such as riparian vegetation clearance in pasture or forest harvesting, I suggest that change from the natural state (probably close to the pre-harvest state in planted forests (Quinn and Wright-Stow 2008)) should be measured as the change in the annual average temperature and/or average daily maximum during summer (December-February

inclusive) measured from either semi-continuous measurements (eg. hourly) or fortnightly spot measurements made at a consistent time of the day.

34. **Dissolved oxygen (DO) - background:** Adequate levels of DO are a fundamental prerequisite for healthy aquatic ecosystems and are typically near 100% of the saturation concentration in undisturbed conditions. DO concentration is determined by the balance of oxygen production by plant photosynthesis during the day, removal by respiration of biota (mainly fungi, bacteria and plants) during the night, and gas exchange with the atmosphere (greatest in shallow streams with turbulent flow). DO levels fluctuate in productive rivers due to the diurnal (day/night) cycles of plant photosynthesis during the day (often increasing levels above 100% saturation) and plant, bacteria and fungal respiration at night. Human activities can increase these fluctuations by enhancing plant growth (eg. through nutrient enrichment and shade reduction) or adding organic matter that increases respiration. DO depletion can be rapid and extreme if the organic matter input stimulates proliferation of unsightly heterotrophic (bacteria and/or fungal) slimes, commonly known as “sewage fungus”. The Manawatu River had a history of sewage fungus blooms and severe night-time deoxygenation, resulting in occasional fish kills, before the inputs of organic material in wastewaters were reduced to meet limits on Biochemical Oxygen Demand (BOD), a measure of the organic content of a water sample, during the mid-1980s “Manawatu River cleanup” (Quinn & Gilliland 1989) (see Barry Gilliland’s evidence to the Hearing Panel).

35. **Dissolved oxygen – standards in the POP:** I support the minimum DO standards of 60-80% of saturation recommended for various LSC classes in the POP (Table D.17). These are based on an analysis of the existing information in the New Zealand and overseas literature on DO effects on freshwater biota, and of the relative sensitivities of the faunas typical of the different LSC classes by Ausseil and Clark (2007). These minimum levels preferably would be best assessed from the diurnal minimum values from continuous monitoring, otherwise from near-dawn spot measurements at critical times of the year (eg. summer low-flows).

36. **Biochemical Oxygen Demand (BOD):** (Note that this is incorrectly termed “Biological Oxygen Demand” in some instances in the POP documents.) BOD is a bioassay measure of the amount of organic matter in water that is relatively degradable and the potential for wastewaters to promote sewage fungus and DO depletion. The standard method involves a five-day incubation at 20° C and hence expressed as BOD_5. Because nitrification of ammoniacal nitrogen to nitrate also reduces DO, BOD_5 may be measured

with addition of a nitrification inhibitor to stop this process in waters with high ammoniacal nitrogen (NH_4) concentrations so that the result is due solely to the oxygen demand of the carbonaceous matter that promotes heterotrophic slimes; in which case the result is denoted as $cBOD_5$. BOD_5 measures both degradable particulate organic matter (not directly available for growth of bacteria and fungi on the stream bed) and dissolved organic compounds that can stimulate bacterial and fungal growth (particularly low molecular weight compounds like lactose, glucose and sucrose with MW < 1000 daltons). Hence, soluble BOD_5 (or soluble $cBOD_5$) is a more useful general predictor of the potential to stimulate these slimes than total BOD_5. The five-day incubation period of the standard BOD test is rather inconvenient for routine monitoring because it requires weekend work (with associated added expense) to read test results on samples set up on a Monday or Tuesday. To get around this, consideration could be given to changing the test to a seven-day BOD (BOD_7), perhaps after developing BOD_5/BOD_7 conversion relationships.

37. **BOD_5 and sewage fungus:** My research carried out in the Manawatu River and in experimental streams concluded that the best practicable method for control of sewage fungus was to limit the daily average $cBOD_5$ due to soluble organics (that is, material passing through a GF/C filter, ie. $scBOD_5$) to < 2 g/m^3, and this was adopted in the daily average concentration limit in the 1998 Manawatu Catchment Water Quality Regional Plan (Rule 1e). The standards for different LSC classes in the POP (<1 or <2 g BOD_5/m^3, Table D.17) are more stringent because: (i) the limits are maxima; and (ii) they include particulate and soluble organics (ie. apply to unfiltered water samples). The 1 g BOD_5/m^3 standard is also at the detection level (for $scBOD_5$) in the Horizons SOE monitoring (email from Kate McArthur of 23/03/2009), leaving no measurable capacity to assimilate further BOD additions in WMZs with this standard. Sewage fungus growth is essentially a stable-flow problem, so that the standards should apply at flows below the 20th percentile (this criterion is used elsewhere in the POP to identify relatively stable flow conditions). I recommend focusing standards on prevention of sewage fungus development by changing the <1 g BOD_5/m^3 and <2 g BOD_5/m^3 standards in various WMZs to *averages* of 1.5 g $scBOD_5$/m^3 and 2 g $scBOD_5$/m^3, respectively. I also recommend applying these standards at flows below the 20th percentile with the averages applying at weekly or greater scales (not hourly or a daily average) to reflect the timescales of BOD impact on sewage fungus.

38. **BOD_5 and DO prediction:** BOD_5 can be used to predict river DO downstream of organic wastewater discharges in large rivers, where the respiration of microbes in the water column dominates river respiration (using the Streeter-Phelps model that accounts

the rates of BOD exertion and stream reaeration). However, the BOD_5/DO relationship is more complex in small-medium stony-bed rivers, like most in Horizons' Region, where the stream bed periphyton communities of algae and bacteria dominate the river respiration. In this situation, effects of wastewater input on DO act through both BOD_5-enhancing heterotrophic microbes and nutrients (mainly N and P) increasing the streambed periphyton biomass, which then increases the streambed respiration and lowers DO at night. This means there is no straight-forward, readily modeled, relationship between BOD_5 and DO that can be applied generally to the rivers in Horizons' Region. Nevertheless, BOD_5 is still a useful indicator of the risk of DO depletion, as it increases with increasing BOD_5, and of sewage fungus growth. The POP's BOD_5 standards appear to aim to manage both these undesirable impacts. It is my opinion that adequate DO will be maintained in the water column of Horizons' rivers if controls on nutrients and organic inputs are sufficient to prevent excessive algal periphyton (as defined by chlorophyll a standards in the POP) and sewage fungus development.

39. **BOD as a monitoring tool:** Experience with the National River Water Quality Network over 20 years was that BOD is an expensive parameter to measure and is only really useful where point source pollution is significant. Hence, I recommend restricting its routine application for monitoring to WMZs that have point source organic pollution issues.

40. **Particulate Organic Matter (POM) standard:** POM is a measure of the organic component of suspended solids (also known as Loss on Ignition or Ash Free Dry Mass). The POM standards in the POP are <2.5 or < 5 g/m^3 at all river flows for different WMZs (Table D.17). These aim to prevent degradation of the stream bed habitat from excessive deposition of particulate organics, in order to protect macroinvertebrate communities; hence the POM standards are linked with Quantitative Macroinvertebrate Community Index (QMCI) standards (Ausseil & Clark 2007b). These compare with the MCWQRP Rule 2d that "The daily average concentration of particulate organic matter shall not exceed 5 g/m^3". Rule 2d was based on findings from a study of the effects of oxidation pond-treated effluent on NZ streams (Quinn & Hickey 1993) that found consistent reductions in the abundance of sensitive invertebrates and QMCI at increases in average POM of 6-43 g/m^3 above an average background level of 0.8 g/m^3, but generally not at increases of <1-3.7 g/m^3 (as argued in more detail in McBride and Quinn 1993).

41. The POM standards in the POP have been criticised (Hamill, 2008) on the basis that the impact thresholds that the standards are derived from Quinn and Hickey (1993) referred to *increases* above background levels upstream of sewage oxidation pond discharges and that Ausseil and Clark (2007) based their argument for POM standards on the effects of increases in suspended solids (SS), not POM. However, McBride and Quinn's (1993) analysis that led to MCWQRP Rule 2d was based on the POM (as outlined above) and I consider that that analysis remains a valid basis for MCWQRP Rule 2d that has been translated and adapted in the POP standards.

42. Hamill (2008) also contends that the POM increases in Quinn and Hickey's (1993) study were part of a suite of multiple stressors (including ammonia, BOD_5, $sBOD_5$, DO and high stream bed respiration) so that relating impacts directly to SS and POM increases is not straightforward. This is a valid point, but pollutant impacts typically involve multiple stressors; natural experiments, such as the Quinn and Hickey (1993) comparison of stream attributes above and below oxidation pond discharges over a range of instream effluent dilutions, provide valuable information for management in real-world situations.

43. POM is a relatively simple/inexpensive and practical variable to measure, compared with BOD, minimum DO and stream bed respiration. It is also related mechanistically to impacts on benthic invertebrates through the effects of excessive amounts of settled POM on stream bed DO. Therefore, I recommend including the 5 g/m^3 POM standard, applied as an average under low-flow conditions (< median flow) at all riverine WMZs, as a means of practicable control of the organic particle load in rivers. I specify low-flow measurements because POM is high naturally under high flows and is only likely to settle and accumulate on the stream bed under stable, low-flow, conditions. POM should be assessed as averages applying at weekly or greater scales (ie. not hourly or a daily average) to reflect the timescales of POM impact on stream bed habitat. However, I consider that this standard should be viewed as provisional and reviewed in an adaptive management context, as more information comes to hand from SOE monitoring. I do not support the 2.5 g/m^3 POM standard recommended for many more pristine WMZs because there is no strong evidence for it being necessary.

44. Horizons' detection limit for POM in its SOE monitoring is high (at 3 g/m^3; email from Kate McArthur on 23/2/09) relative to the standards suggested, indicating that there are currently technical difficulties with use of this variable. However, this detection limit can be reduced if larger water samples are collected when the samples have low POM levels: this is usually obvious from the clarity/low level of settled material in the sample. For example, Quinn and Hickey (1993) detected background POM levels (above

wastewater discharges to eight NZ streams) of 0.5-1.1 g m^{-3} from large (2-litre) water samples. NIWA's Hamilton water quality laboratory has a standard detection limit for POM of 0.5 g/m^3 for analyses on 1-litre water samples.

45. **Value of biological indicators of ecosystem health:** Biological indicators can provide direct measures of whether or not the management of stream habitat and water chemistry are achieving their aim of protecting ecosystem health, and whether this is getting better, worse, or staying the same over time. Biological monitors also integrate effects over various timescales, in relation to the life spans of the indicators, and may identify impacts of sporadic impacts (eg. chemical spills) that are not detected by set interval water quality sampling (eg. monthly grab samples). As with physico-chemical indicators, biological indicators can be adopted as management objectives or as ecosystem health standards. The POP takes the latter approach, setting standards for periphyton biomass and percentage cover, and for Quantitative Macroinvertebrate Community Index (QMCI) levels in Schedule D (Table D17).

46. **Periphyton cover/biomass:** Periphyton cover is a useful biological indicator of both ecosystem health and of the suitability of streams for recreation. Nuisance periphyton blooms are usually a symptom of a system stressed by factors like over-supply of nutrients and high temperatures, which increase algal growth rates but stress some invertebrate grazers. Guideline upper limits for periphyton cover and biomass to protect aquatic ecosystem health and aesthetics have been developed by the Ministry for the Environment, as discussed in more detail in the evidence of Dr Barry Biggs.

47. **Summary of National Rivers Water Quality Network at seven sites in Horizons' Region:** Percentage cover of wadeable areas of the river bed has been assessed since 1990 during monthly visits seven sites in Horizons' Region by the National Rivers Water Quality Network when river flow conditions allow safe wading (ie. between ½ and $^2/_3$ of visits). These assessments focus on potential nuisance periphyton; the percentage cover as mats (> 2 mm thick) or filamentous growths is assessed visually at 10 equally spaced points across the wadeable area of a river cross-section, typically covering 25-50% of the river width at these sites. Recent analyses for the period 1990-2006 indicate that: (i) average annual maximum cover by filamentous algae exceeded the MFE guideline of 30% at three sites (Whanganui River at Te Maire, Manawatu River at Weber Rd (upper catchment) and Opiki River downstream of Palmerston North; and (ii) trend analysis (Spearman r_s) indicated statistically significant ($P < 0.05$,) increases in the Whanganui River at Te Maire and the Rangitikei River at Kakariki and weak trend of declining filamentous cover ($0.1 > P > 0.05$) at Manawatu at Weber Rd. Although these

results cover a small number of sites, they indicate that there are sites within Horizons' Region where periphyton cover degrades aesthetic conditions.

48. **Macroinvertebrate indicators of aquatic ecosystem health:** Benthic macroinvertebrates are commonly used as indicators of stream and river condition because they play key roles in stream ecosystems, are relatively easy to sample and identify, and the responses of community composition to ecosystem condition is reasonably well understood and can be summarised in metrics. There are a variety of ways to analyse invertebrate data, but the Macroinvertebrate Community Index (MCI) is generally accepted as the most robust metric for assessing the river condition in State of the Environment assessment in New Zealand. MCI assigns pollution sensitivity scores, from 1 (low) to 10 (high), for each invertebrate type (usually at genus level) collected at a site, then multiplies the average of these scores by 20 to give values that could theoretically fall between 20 and 200. MCI quality classes have been proposed as excellent if more than 119, good if 100-119, fair if 80-99, and poor below 80 (see Stark 2008 report to Horizons). Recently, NIWA has developed methods (described by Dr John Leathwick at the November 2008 NZ Freshwater Sciences Society Conference) to model the MCI at each river reach throughout New Zealand using a combination of catchment and river geographic information, model predictions of nitrogen load (as a development index) and a large database of macroinvertebrate information. These models predict both the current MCI and potential MCI predicted by the model, with nitrogen load set to zero and complete native vegetation cover in the upstream catchment. These potential MCIs provide another benchmark for the natural condition and range from 130 to 137 for the seven NRWQN sites in Horizons' Region (*pers. comm.* Dr J Leathwick, NIWA). These predictions are consistent with the average MCI of 138 for the Mangawhero River at the Department of Conservation's headquarters within Tongariro National Park (Stark 2008).

49. MCI vs QMCI as State of the Environment (SOE) indicators: The QMCI is a quantitative version of the MCI that includes information on the sensitivity scores of each individual invertebrate, rather than each type in MCI. Schedule D of the POP includes QMCI standards of 5 or 6 for different Water Management Zones. QMCI is more sensitive than the MCI for comparing communities at sites upstream and downstream of effluent discharges, because the downstream drift of invertebrates can result in collection of a few individuals of sensitive taxa that could not persist in the longer term. However, it tends to be a more variable metric and less suitable for SOE monitoring than the MCI. Hence, I support the recommendation of Stark (2008) to use the MCI as the core macroinvertebrate index of ecosystem health, but to use the QMCI for monitoring

impacts of discharges by comparison of sites upstream and downstream of inputs. I recommend substituting the MCI values of 100 and 120 for QMCI standards of 5 and 6 in Schedule D Table D.17.

50. **Need for water quality improvement in Horizons' Region:** A recent report to Horizons (Stark 2008) summarised the Region's SOE biomonitoring using macroinvertebrates at 21 sites sampled on 6-9 occasions (usually annually during summer) during 1999-2007. The National Rivers Water Quality Network also includes 7 sites in the Horizons' region where macroinvertebrates have been sampled annually in summer during 1990-2007 using similar methods to Horizons' SOE monitoring. Two of the NRWQN sites are also Horizons SOE sites and had average MCIs for 1999-2007 that were within 4 and 8 units of each other, indicating that the two programmes were yielding broadly similar results. Of the 21 sites examined in Stark's report, the MCI suggested that one site had "excellent" stream health, five were "good", 12 were "fair", and three were "poor". The average MCI scores from the longer NRWQN programme indicate a similar pattern (Fig. 1). Four sites were classed as "good" (Rangitikei River at Mangaweka, Rangitikei River at Kakariki, Whanganui River at Te Maire, and Manawatu River at Weber Rd), two as borderline "fair-good" (Whanganui River at Paetawa and Manawatu River at Teachers College), and the Manawatu River at Opiki was classed as "fair". The NRWQN sites at Paetawa (lower Whanganui River) and Opiki (lower Manawatu River) had lower MCI than predicted by NIWA's general NZ model, which probably reflects the high sediment levels at Paetawa and influences of point source discharges at Opiki. Both the MCI quality classes and comparisons with modeled potential MCI for pristine conditions indicate that there is ample scope for improvement in river ecosystem health in Horizon's Region.

51. **Trends in river ecosystem health:** Stark (2008) analysed trends in MCI and QMCI at 21 sites over 1999-2007 and found that one of both metrics had statistically significant positive trends (without allowing for false discovery rates) at 3 sites (Makakahi River at Konini, and Whanganui River at Te Maire and Whanganui Estuary sites) and negative trends at two sites (Manawatu at Teachers College and Oroua River at Awahuri Bridge). However, none of the seven NRWQN sites showed significant trends in MCI over the period 1990-2007 (Fig. 2).

52. **General influences on timescales for recovery of values if standards are met:** The timescales for recovery of biota once habitat quality has been restored (eg. water quality standards are met) are expected to vary in relation to the life cycles of species and the connectivity between the restored habitat and sources of the sensitive biota that have

been lost. Short-lived organisms, such as in bacterial slimes and periphyton, respond very rapidly to the cessation of light/nutrient/BOD inputs, whereas it takes years for populations of long-lived species such as eels to re-establish natural abundance and population size structure. Species that have highly mobile phases (eg. native fish that migrate between freshwater and the ocean) will recover more rapidly than more sedentary species, such as freshwater crayfish and non-migratory native fish species. Among aquatic insects, caddisflies would be expected to disperse more rapidly between adjacent catchments than mayflies, owing to the longer adult aerial phase of caddisflies. Having protected headwaters is expected to increase the recovery rate of downstream reaches by, for example, (i) providing a reservoir of colonist invertebrates that can expand downstream through the natural drift of larvae and flight of adult insects along the stream; and (ii) pheromone/attractants from resident native fish enhancing upstream migration of juveniles into the stream system from the sea. On the other hand, migration barriers to fish, such as dams and floodgates, may prevent effective recolonisation without mitigation measures to address this issue. Similarly, if there are no sources of invertebrate recolonists within a catchment or in nearby catchments, pre-existing biota are unlikely to ever be restored without active translocation.

53. **Timescales for habitat restoration:** The restoration of suitable habitat can be delayed considerably after establishing restoration measures, due to time required for: (i) riparian forest to regrow sufficiently to restore shade and natural inputs of leaf litter and wood, as natural stream food resources and structural elements of stream habitat; and (ii) lags in the system's response to mitigations/restoration due to ongoing input of contaminants stored in soils (eg. Cadmium, DDT), ground-waters (eg. nitrate) and stream banks (eg. sediment).

54. Examples of restoration timescales: My research on the effects of forest regrowth after logging on stream shade and temperature found that the rate of temperature recovery was inversely proportional to stream size. After clearfelling, the daily maximum summer temperatures of small streams (2-4 m wide channels) during summer took about 6-8 years to return to those of reference forest streams, whereas this was predicted to take about 12 years in 6-12 m wide streams (Quinn & Wright-Stow 2008). Responses of macroinvertebrate indices and community structure to riparian revegetation in pastoral farms, and to forest regrowth after clearfell logging, have also been found to be more rapid in small than medium sized streams. MCI/QMCI and macroinvertebrate community composition showed considerable, though still not complete, recovery within 7-10 years in response to riparian restoration of small-medium pastoral streams (<4 m wide) in Waikato catchments with headwaters or adjacent streams in native forest. I have found

similar timescales of macroinvertebrate index recovery after clear-fell logging have been observed in small Coromandel streams. These recovery timescales likely to be as short as possible because the studies were undertaken in near optimal conditions for natural biota recolonisation in small streams. I would expect restoration of biota in larger rivers restoration to occur over decadal timescales.

55. **Reviews of Horizons' reports:** I acted as an external reviewer of Horizons' reports that underpin the POP on River Classification (Ausseil & Clark 2007c), Values (Ausseil & Clark 2007a), Standards (Ausseil & Clark 2007b), and an early draft of the Water Quality Framework report (McArthur & Roygard 2008).

56. I supported the River Classification report as a pragmatic, science-based approach that provides a framework for water management and policy around managing life supporting capacity. The Values report was also seen as a robust method to defining 23 aquatic-related values in four classes and mapping these to enhance understanding of what values occur where. Combined with the Water Management Zones framework, this provides a rational and sound basis for allocating standards to protect the key values. As outlined in Section 2 above, I support the promotion of numeric water quality standards by Ausseil & Clark (2007b), applied within the frameworks of water management zones and life supporting capacity classes in the Proposed One Plan. There are some changes and additions to the standards that I have recommended after further reflection (see sections above).

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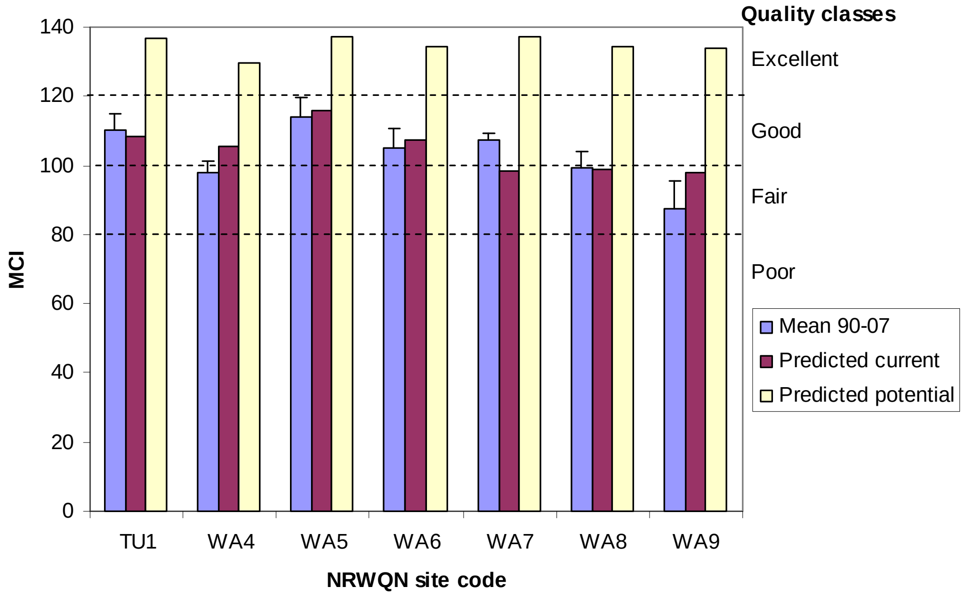

Figure 1. Summary of means (+ 95% confidence intervals) of MCI at National River Water Quality Network (NRWQN) sites in Horizons' Region from 1990-2007 and current and potential MCI values predicted by the NIWA model (pers. comm. John Leathwick). Site codes: TU1 = Whanganui River at Te Maire; WA4 = Whanganui River at Paetawa; WA5 = Rangitikei River at Mangaweka; WA6 = Rangitikei River at Kakariki; WA7 = Manawatu River at Weber Rd; WA8 = Manawatu River at Palmerston North Teachers College; and WA9 = Manawatu River at Opiki.

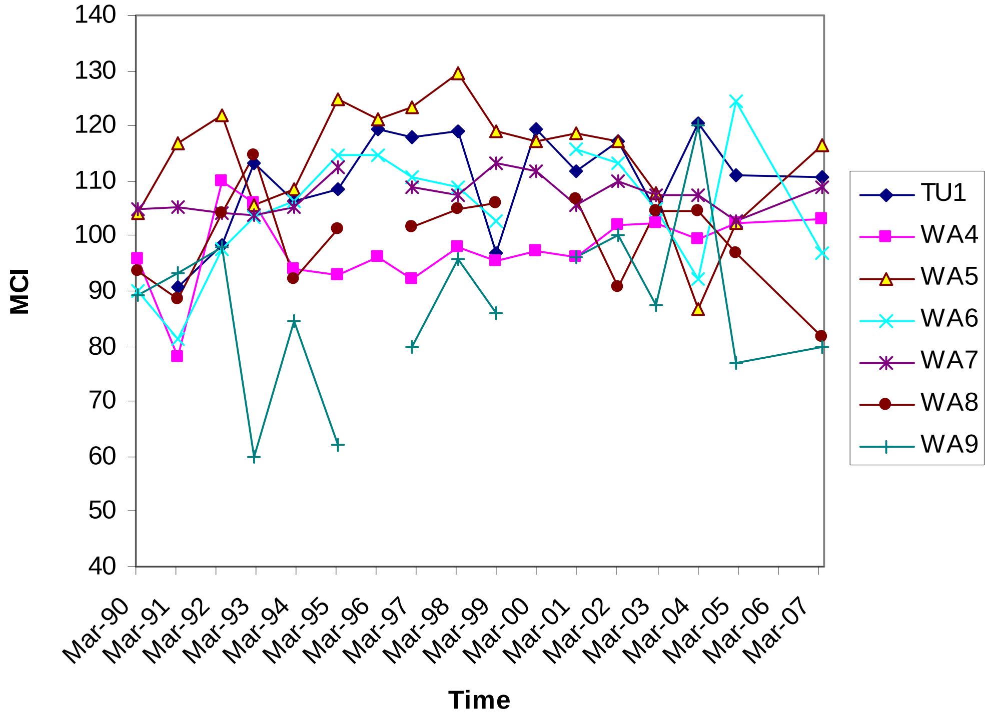

Figure 2. Variations in MCI at seven NRWQN sites over 1990-2007 showing lack of strong trends. Note that several sites had unusual MCI's in March 2004 following severe flooding. Site codes: TU1 = Whanganui River at Te Maire; WA4 = Whanganui River at Paetawa; WA5 = Rangitikei River at Mangaweka; WA6 = Rangitikei River at Kakariki; WA7 = Manawatu River at Weber Rd; WA8 = Manawatu River at Palmerston North Teachers College; and WA9 = Manawatu River at Opiki.