BEFORE THE HEARINGS PANEL

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

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SECTION 42A REPORT OF DR JOHN R. ZELDIS
ON BEHALF OF HORIZONS REGIONAL COUNCIL

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1. INTRODUCTION

My qualifications/experience

1. I am currently employed at NIWA where I am a Principal Scientist, project leader and Marine Group Manager. I have 25 years post-doctoral experience as a marine scientist and hold the qualifications BSc. (1976). Dip. Sci. (1978) and PhD (1983) in marine biology, from University of California at Santa Cruz and University of Otago.

2. Over my career I have worked across the following marine science disciplines: physiological ecology and zoology, shoreline ecology, plankton ecology, fisheries science, and biological, chemical and physical oceanography. Within these disciplines I have published about 45 papers in peer-reviewed, international journals and books. My research over the last 10 years has focused on chemical oceanography, nutrient cycling and primary production in coastal waters, within which I participate in national and international-funded research programmes. I have worked closely with industry and with numerous New Zealand Regional Councils and Territorial Authorities (ie. Auckland, Waikato, Tasman and Canterbury Regional Councils, Christchurch City Council) to advise on catchment and oceanic nutrient-related issues in their coastal management areas. Recently, I have been leading research investigating the restoration of ecosystem health of the Avon-Heathcote Estuary (Christchurch) prior to and following the commissioning of the Christchurch Wastewater Treatment Plant ocean outfall. I have produced more than 40 environmental assessments and consultancy reports covering fisheries assessments, mussel farm impacts, ocean outfalls, environmental variability monitoring, and nutrient source/pollution issues in estuaries and coastal zones. I have designed frameworks for managing environmental performance of large-scale aquaculture development, and assisted local government and industry in their implementation (Auckland Regional Council, Environment Waikato, Wilson Bay Group A.) I have testified in hearings before the Maori Land Court in relation to an application to develop taiāpure over Akaroa Harbour, and before the Environment Court in hearings over issuing permits to discharge Christchurch Wastewater Treatment Plant effluent via a coastal outfall.

3. I have read the Code of Conduct for expert witnesses and I agree to comply with it.

My role in the Proposed One Plan

4. I have no previous involvement with the Proposed One Plan. My current role is to assemble and present evidence according to the ‘Scope of evidence’, below.

Scope of evidence

5. My evidence will discuss: 1) the effects of estuarine and coastal nutrient enrichment from rivers; 2) potential for and evidence of enrichment in Horizons' Region with regard its effects on environmental values in its estuaries and adjacent coasts; 3) the need for water quality (in particular, nutrient, but including other) standards in the estuaries and coastal areas of the river systems of the Region; and 4) the appropriateness of the draft standards and their levels as proposed in the proposed Schedule H.

2. EXECUTIVE SUMMARY OF EVIDENCE

6. Eutrophication is a global problem, arising from excessive nutrients from terrestrial sources entering the coastal zone and leading to degraded sediment chemistry, suboxic and anoxic water and sedimentary habitats for plants and animals, nuisance algal blooms, and reduced biodiversity.

7. In New Zealand, lowland river and stream nutrient pollution, especially with intensified rural land use, is an increasingly serious threat to coastal watersheds and estuaries, with eutrophic and microbiological water quality impacts. Numerous estuaries around the country are now so impacted.

8. In the Manawatu-Wanganui (Horizons) Region, lowland reaches of major rivers are among the most highly nutrient-loaded in New Zealand. It is therefore important to examine whether these loads are causing eutrophic conditions and affecting values in the Region's estuaries and coastal waters.

9. Nitrogen is the key contaminant of concern with regards to estuarine and coastal eutrophication, acting as the dominant limiting nutrient for growth of phytoplankton and 'nuisance' species of macroalgae.

10. Direct effects of nutrient enrichment (eutrophication) in estuaries include: 1) excessive water column and benthic primary production (organic matter), leading to increased oxygen demand and hypoxia (low oxygen), animal mortalities and displacement; and 2) undesirable algal blooms and shifts in community structure. On the estuary bed, excess micro-algal primary production can lead to degradation of seagrass beds and formation of nuisance macroalgal beds, which can smother large tracts of shore area, severely impacting habitat quality for invertebrates and higher food web levels. These also form a public nuisance when they wash ashore and decompose, causing unpleasant odours.

11. Eutrophication reduces ecological, environmental and societal values of coastal areas, lowering their use and aesthetic and economic valuation by the public. These include recreational, food gathering and aesthetic regard, and both use and non-use values. These relate to a number of values in the recommended Schedule H, Table H2 of the Proposed One Plan, including Life Supporting Capacity and other ecosystem values, contact recreation, shellfish harvesting, amenity values, and capacity to assimilate pollution.

12. Water quality concentration-based standards and targets are important for the control of eutrophication in estuaries. They are easily monitored and understood by regulators and the public.

13. I support the overall approach of the Proposed One Plan to water quality management, ie. of identifying the community's key values for estuaries and coastal waters, and defining water quality concentration-based standards to protect them.

14. However, nutrient standards should be set considering local physical and ecological conditions. In some estuaries, growth of nuisance macroalgae may not occur, irrespective of overlying nutrient concentrations, if they are highly turbid (low light) and/or have only small amounts of emergent or shallow subtidal habitat capable of supporting such growth. Also, phytoplankton growth may not lead to eutrophication even within high nutrient concentrations, if estuarine flow to the coastal sea is so rapid that bloom formation and sedimentation within the estuary is prevented.

15. It is therefore important to consider key defining characteristics of estuaries when setting and assessing concentration-based standards. These include: 1) the physical setting; 2) the types of plants involved; 3) the amounts of nutrients loaded to the system, how much these are diluted within the estuary, and the water residence time and flushing rates to the sea.

16. A number of NIWA tools were used to assess nutrient concentrations in estuaries in Horizons' Region (for which almost no actual nutrient concentration sampling exists) using simple hydrodynamics, and data on estuary volume, high and low tidal area, tidal prism, freshwater discharges near the terminal reaches of the rivers flowing to each estuary, and total nitrogen loads for these terminal reaches. The nutrient levels were predicted using an index, Dissolved Concentration Potential (DCP) which can be used to gauge the susceptibility of estuaries to over-enrichment.

17. The estimated values were compared with DCP in a meta-analysis of US estuaries to gauge the relationship of DCP to trophic status (ie. non-eutrophied, moderately eutrophied, very eutrophied), which corresponds to DCP less than 100 mg/m^3, 100-1000 mg/m^3 and greater than 1000 mg/m^3, respectively.

18. Results showed that in the major estuaries (Whanganui, Whangaehu, Rangitikei, Manawatu) and the minor estuaries, freshwater input is similar to, or exceeds, the tidal prism in controlling estuary volume. The freshwater nutrient loads are high, similar to the load to the Avon-Heathcote Estuary, which includes Christchurch's wastewater. The DCP values are between 400 and 800 mgN/m^3, which the meta-analysis shows are capable of rendering the estuaries 'medium' in terms of susceptibility to eutrophication. Such levels are well above those saturating for growth of phytoplankton and nuisance macroalgae such as *Ulva* (about 70 mgN/m^3).

19. Although the DCP results suggest the estuaries are susceptible to eutrophication, we need to evaluate whether they actually are. The available data for major estuaries of the Region do not show overt signs of eutrophication, for dissolved oxygen (DO) or, in general, for nuisance algal growth. An exception is Manawatu Estuary, where macroalgae bloom occurs under high nutrient loading in a small intertidal area, which has built up in previous decades with a change in location of the estuary mouth. Other than this, there is no other in-estuary monitoring on which to evaluate the trophic status of estuaries in Horizons' Region.

20. It would appear that the reason extensive macroalgae, low DO and other eutrophic symptoms are generally not present in these estuaries is the due to their physiography. They generally have no or very little intertidal area capable of supporting attached macroalgae, and they are turbid. They are river-dominated, with frequent low salinity, and are rapidly flushed (flushing times generally < 0.5 day) such that phytoplankton blooms do not form. These estuaries essentially act as 'pipelines to the sea' for their high nutrient loads, with negligible biological processing by water column or benthic algae during transit.

21. In addition to elevated nutrients, necessary conditions for macroalgal bloom formation are the availability of substrate, appropriate light levels and possibly high salinity (these conditions may be correlated where there are intertidal areas built up that are only inundated at high tide). Except to some extent in Manawatu Estuary, such conditions appear not to be met in Horizons' estuaries. This is in contrast to the Avon-Heathcote Estuary (Christchurch) and other New Zealand mudflat-dominated estuaries with

macroalgal bloom problems. There, attached algae are constantly bathed in relatively high salinity waters with elevated nutrients, and often exposed to high light levels.

22. The major Horizons' Region river-estuary systems transport sediment loads that are high on a New Zealand-wide basis – similar in absolute magnitude to the large rivers of Canterbury and the South Island West Coast. Should geomorphic conditions change, allowing this transport to create intertidal habitat (which appears to have happened in the Manawatu Estuary), it is possible that symptoms of macroalgal eutrophication will appear more commonly.

23. In the energetic Seawater Management Zone of the Manawatu-Wanganui coastline, water quality shows considerably elevated levels (200-600 mg/m^3 total nitrogen 90th percentile ranges) *cf* 'normal' coastal site levels (generally less than 10-30 mg/m^3) such as found off Lyttleton Heads, Christchurch, or in Tamaki Strait, Auckland. Horizons' Seawater Coastal Marine Area (CMA) sampling sites are adjacent to their estuaries and it is likely they are reflecting their high estuarine nutrient loads. However, without direct surveying it is unknown if they are generating elevated phytoplankton or attached algal proliferations in adjacent shore areas over significant spatial extents. Such surveying is recommended and should incorporate salinity measures, which over time should help differentiate nutrients delivered by high river flow events, from possible diffuse loading (ie. from coastal sands areas). Satellite remote sensing analysis may also be useful in this regard.

24. For estuaries in Horizons' Region, it is advised that nutrient levels be held at or below their present levels, as they are already high and, should changes occur in estuarine physiography (increased intertidal area, decreases in turbidity), they could easily generate eutrophic problems. This applies primarily for nitrogen, because it is the key limiting nutrient in these systems, but applies also to phosphorus, which also is likely to be present at high concentrations. Based on the DCP analysis, and considering the probable composition of total N in the loading (potentially 50% inorganic), it is likely that the 167 mg/m^3 soluble inorganic nitrogen (SIN) standard proposed for most estuaries in the recommended Schedule H of the Proposed One Plan reflects current average levels or a reduction in them, and is therefore suitable.

25. The standard for the Manawatu Estuary should not be set higher than 167 mg/m^3 (currently the standard is set at 444 mg/m^3 in the Proposed One Plan), as this estuary has already shown eutrophic symptoms and has high value internationally as a Ramsar site. It must be noted that the DCP method is only approximate, and more accurate

determinations of estuarine nutrient levels should be obtained with direct estuarine sampling. For the Seawater areas, the same recommendations apply and should be subject to modification based on surveys.

26. I recommend the 444 mg/m^3 soluble inorganic nitrogen (SIN) standard for the Manawatu Estuary sub-zone is reduced to 167 mg/m^3.

27. These standards are much higher than the ANZECC (2000) guideline trigger levels (about 30 mg/m^3 soluble inorganic nitrogen) for 'slightly disturbed estuarine water'. These guidelines are based on oligotrophic (low-nutrient) waters of south-east Australia (as of 2005 no nutrient trigger levels had been developed for NZ waters: Bolton-Ritchie and Main, 2005). Another standard, discussed in context of the Avon-Heathcote Estuary and developed for reversing eutrophication in the Potomac Estuary (US), recommended much higher criteria (300-500 mg/m^3 soluble inorganic nitrogen). The standards proposed for most estuaries in Schedule H of the Proposed One Plan are somewhat lower than this (110 - 167 mg/m^3), but the proposed standards are considered reasonable, given the apparent susceptibility to eutrophy in Horizons' estuaries upon changes in geomorphology, such as has occurred in the Manawatu Estuary.

28. SIN is largely composed of two N forms in estuaries, being nitrate (NO_3^-) and ammonia ion (NH_4^+ - usually called ammonium). However, relatively low concentrations of un-ionised ammonia (NH_3) can occur under conditions of high ammonium concentration, and it is toxic to marine life.

29. I support the limit of 400 mg/m^3 ammoniacal nitrogen applied in Schedule H of the Proposed One Plan to provide for protection of marine species. This standard will be met by default with an SIN standard of 110 or 167 mg/m^3 in the Estuarine Sub-zones.

30. The ammonium trigger levels are, to some extent, dependent on pH, temperature and salinity, so it is recommended that those variables be routinely measured at all future water quality sampling which includes nitrogen and phosphorus.

31. For dissolved oxygen (DO), I recommend that the limit for those estuaries notified for a 60% of saturation DO minimum (ie. the Mowhanau, Hokio and Whanganui estuaries) be increased to 70%.

32. The proposed standard of 90% of DO saturation in the Seawater Management Zone is satisfactory. Lower river DO standards should be set with these estuarine standards in mind.

33. I recommend retaining the toxicity standards as proposed in recommended Schedule H.

34. I recommend standards for pH, temperature, BOD_5, and POM are removed from recommended Schedule H.

35. For microbiological standards, enterococci should be included because it is the appropriate indicator to use for faecal contamination in seawater. An Alert trigger level of 140 enterococci cells/100mL is recommended by MfE/MoH Recreational Water Quality Guidelines for safe contact recreation and should be monitored in waters with conductivity > 200 µs/cm. The results of monitoring should be graded using the Sanitary Inspection Category (SIC) system and Microbiological Assessment Category (MAC), which provides a measurement of the actual water quality over time. This estuarine sampling should be included in light of generally poor bacteriological water quality in the Region's rivers. It is likely that efforts to improve bacteriological water quality in the rivers will improve overall water quality in the estuaries.

36. I recommend the enterococci standards for Seawater Management Zones in recommended Schedule H of the Proposed One Plan are retained.

37. I also recommend that standards for faecal indicator bacteria are applied to the Estuarine Sub-zones as follows: when waters in Estuarine Sub-zones have conductivity > 200 µs/cm, the enteroccoci standards shall be the same as the standards for the Seawater Management Zones, when conductivity < 200 µs/cm, the proposed *E. coli* standards for rivers and streams shall apply.

38. Standards as applied for periphyton in freshwater are not appropriate in the estuarine context. I recommend removal of the periphyton standards (both % cover and chlorophyll *a* $/m^2$) from the Estuary Sub-zones proposed in Schedule H, and a higher chlorophyll *a* $/m^3$ standard for Seawater Management Zones. To account for nuisance macroalgal growth in the Estuarine Sub-zones, I recommend a standard of no more than 20% cover of shore surface area by macroalgae be added to Schedule H.

39. It is suggested that monitoring be put in place to detect change in marine filamentous algae, macroalgae cover and phytoplankton concentration, which at the present time appears to be low in most places. A focus on the Manawatu Estuary is recommended, given the importance of the estuary as a Ramsar site and its apparent geomorphic and macroalgal changes. Given the high concentrations of nutrients in coastal sampling to date and anecdotal observations of plankton blooms in the Region, it is recommended

that sampling for phytoplankton be incorporated in the mouths and adjacent coastal areas. If deemed necessary, monitoring and compliance for cyanobacteria could be initiated.

40. For visual clarity, black disc readings as exist for the estuaries in Horizons' Region are far more turbid than the standard proposed for freshwaters, which probably reflects the state of the lower major rivers and the likelihood that estuaries may experience higher turbidity naturally due to erosion, tidal resuspension, flocculation etc.

41. I recommend removal of the Turbidity standards from the Seawater Management Zone and the Estuary Sub-zones (as discussed in the evidence of Dr Davies-Colley).

42. I do not recommend the application of a minimum clarity standard (ie. 1.6 m horizontal visibility) for the estuary sub-zones, because of the low natural clarity (as discussed above). However, I do support the recommendation of Dr Davies-Colley for a 20% change in horizontal visibility limit to apply to Estuary Sub-zones, and I recommend monitoring be put in place to detect changes in clarity that may accrue with river water quality changes.

43. I support the recommendations of Dr Davies-Colley for no more than a 10% change in euphotic depth for estuarine and coastal waters

3. EVIDENCE

International, national and local situation

44. Coastal marine ecosystems worldwide are degraded by eutrophication arising from excessive nutrients from terrestrial sources entering the coastal zone (Valiella et al., 1997; NRC, 2000). The resultant excessive primary production (formation of organic matter through plant growth), and its respiration (consumption of organic matter and oxygen) lead to severely degraded sediment chemistry, suboxic and anoxic water and sedimentary habitats for plants and animals, nuisance algal blooms (see Figure 1), and reductions in biodiversity of estuarine plants and invertebrates, with follow-on effects on higher groups such as fish and birds.

45. New Zealand lowland river and stream nutrient pollution, especially with intensified rural land use, is an increasingly serious threat to coastal watersheds and estuaries (eg. Environment Canterbury (ECan) Annual Report, 2008; Hauraki Gulf Forum, 2008). Of New Zealand's lowland rivers, about half fail to meet the national guidelines for faecal

coliforms and nutrients (MfE, 2004) and these feed directly to our coasts. Nutrient pollution is, therefore, a common theme that links our catchments and coastline, both rural and urban. The Department of Conservation (DOC), in its Draft New Zealand Coastal Policy Statement 2008 (DOC, 2008) has formally notified maintenance of coastal water quality and minimisation of ecological effects of discharges among its Objectives and Policies. Similarly, the NZ Biodiversity Strategy (MfE, 2000) has recognised nutrient pollution and consequent eutrophication of coastal waterways as serious threats to marine ecosystems and biodiversity.

46. New Zealand has numerous estuarine areas with excessive catchment-derived nutrient inputs arising from rivers, drains and industrial and municipal wastewater plants, which put large volumes of nutrient-rich run-off and wastewater into estuaries. These include Manukau and Tauranga Harbours (Vant *et al.,* 1998; de Winton *et al.,* 1999), Orakei Basin (Auckland), Whangamata Estuary, Moutere Inlet (Nelson), Ahuriri Estuary (Napier), Titahi Bay (Wellington) (Barr, 2007) and the Avon-Heathcote/Ihutai estuarine system (Christchurch) (Bolton-Ritchie and Main, 2005; ECan, 2008).

47. In Horizons' Region, lowland reaches of major rivers are among the most highly nutrient-loaded in New Zealand. This was demonstrated in context of all major North Island rivers (Figure 2) in an analysis using the FINZ database (NIWA, 2004) – based on the Spatially Referenced Regressions on Watersheds (SPARROW) Model[1]), used to derive the annual mean terminal reach total nitrogen loads of rivers. It is therefore important to examine whether these loads are causing eutrophic conditions and affecting values in the Region's estuaries and coastal waters.

48. Nitrogen is the key contaminant of concern with regards to estuarine and coastal eutrophication, as demonstrated in bioassay experiments, and large-scale ecosystem experiments and studies (NRC, 2000), in which nitrogen additions or nitrogen+phosphorus additions stimulated phytoplankton and macroalgal growth, but phosphorus additions alone did not. Other work (eg. Pedersen and Borum, 1996) has shown these effects to be most marked in nuisance macroalgae (ie. fast-growing, ephemeral algae such as *Ulva* (see below)) as opposed to perennial macroalgae (eg. kelps) or seagrasses, accounting for the former group's high responsiveness to excessive nutrient loading.

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[1] SPARROW was developed by US Geological Survey for prediction of total nitrogen loads at the outlets of major watersheds. It uses independent variables for nitrogen prediction including point-source loads, fertiliser application, livestock waste production plus factors such as temperature, soil permeability and stream density, to accumulate nitrogen loads down-catchment based on catchment characteristics, land-use and in-river parameters. SPARROW is verified with water quality monitoring data, and high values of coefficients of determination of accuracy of its estimates of in-water total nitrogen loads (0.87) have been determined in US studies relating SPARROW estimates to in-stream monitoring (NRC, 2000).

Eutrophication effects

49. Direct effects of nutrient and organic matter enrichment in estuaries can include excessive water column primary production, leading to increased oxygen demand and hypoxia (low oxygen), animal mortalities and displacement, undesirable algal blooms and shifts in community structure (summarised in NRC, 2000 and described further below). On the estuary bed, excess micro-algal primary production can lead to degradation of seagrass beds and formation of undesirable macroalgal beds. *Ulva spp*. (sea lettuce) and *Gracilaria spp.* can smother large tracts of shore area, severely impacting habitat quality for other invertebrates as underlying sediments turn anoxic. These also form a public nuisance when they wash ashore and decompose, causing unpleasant odours (eg. Soulsby *et al.,* 1982). Benthic invertebrate communities are critical in estuaries because they affect sediment structure and chemical function, and support higher food web elements such as fish and birds. Invertebrate biomass can increase with nutrient-driven increased food supply (eg. Essink, 2003). However, macroalgal blooms can smother their habitats, generating hostile physico-chemical environments in underlying sediments, with burrowing bivalves (ie. cockles, etc) being forced to the surface, exclusion of surface deposit feeders, and invertebrates declining in abundance (eg. Raffaelli *et al.,* 1998). Eutrophication reduces ecological, environmental and societal values of coastal areas, lowering their use and aesthetic and economic valuation by the public (reviewed in NRC, 2000). These include recreational, food gathering and aesthetic regard, and both use and non-use values. In context of Schedule H, these relate to a number of values in Table H2, including Life Supporting Capacity and other ecosystem values, contact recreation, shellfish harvesting, amenity values, and capacity to assimilate pollution.

Importance of standards and overall approach of the Proposed One Plan

50. Water quality concentration-based standards and targets are important for the control of eutrophication in estuaries (EPA, 1998; NRC, 2000). They are easily monitored and understood by regulators and the public. I therefore support the overall approach of the Proposed One Plan to water quality management, ie. of identifying the community’s key values for estuaries and coastal waters and defining water quality concentration-based standards to protect these values within the frameworks of CMA estuarine and Coastal Water Management Sub-zones in Schedule H. This approach is consistent with the effects-based philosophy of the Resource Management Act 1991. My experience is that marine resource stakeholders are more likely to engage with environmental management when they identify with the target values and can see the linkages

between their activities and the water quality targets (or standards) designed to protect these values (eg. Zeldis *et al.,* 2005).

Setting and assessing water quality standards for estuaries

51. While concentration-based nutrient standards are beneficial, they should be set in consideration of local physical and ecological conditions. For example, growth of nuisance macroalgae may not occur in some estuaries, irrespective of overlying nutrient concentrations, if they are highly turbid (low light) and/or have only small amounts of emergent or shallow sub-tidal habitat capable of supporting such growth. Also, phytoplankton growth may not lead to eutrophication even within high nutrient concentrations, if estuarine flow to the coastal sea is so rapid (ie. less than the time-scale of cell division) that bloom formation and sedimentation within the estuary is prevented (NRC, 2000). Finally, estuaries badly eutrophied with nuisance macroalgae may exhibit only moderate concentrations of nutrients, simply because of extremely rapid nutrient uptake, nutrient storage and conversion to algal biomass and detrital organic matter (NRC, 2000; Bolton-Ritchie and Main, 2005). It is the loading rates (ie. nutrient mass delivered per unit time) to such systems which drive their eutrophy, not the nutrient standing stocks.

52. It is therefore important to consider key defining characteristics of estuaries when setting and assessing concentration-based standards. These include (NRC, 2000):
    i. **Physiographic setting** – morphology and major biological communities. An example is the hypsography of the estuary (the aerial extent of elevated land), which determines the area able to be colonised by attached aquatic vegetation, along with substrate type. Physiography strongly determines the primary production base (below).
    ii. **Primary production base** – plants with unique requirements (eg. emergent marshes, attached macroalgae, benthic microalgae, seagrasses and phytoplankton), that have unique requirements of temperature, salinity, substrate, light and nutrient loading.
    iii. **Nutrient loading** – total amount of inorganic and organic loading from upstream and the sea.
    iv. **Dilution** – whether the nutrient load is distributed over a large or small estuary area or volume is related to mixing in the estuary and the entire estuary size, and has a strong relationship with eutrophication (Nixon, 1992).
    v. **Water residence time and flushing** – is related to physical conditions and to biotic and chemical conditions. If phytoplankton cannot reproduce before being

exported, or if organic matter cannot be mineralised to algal nutrients before export, they will not cause eutrophication. On the other hand, if residence time is long relative to these processes, phytoplankton and nutrients can build up to high levels. This applies to both the enclosed areas of the estuaries proper, and the open coastal receiving waters.

Key Points

- Internationally and nationally, eutrophication of estuaries and coastal waters is a concern that can cause reduced oxygen availability, nuisance algal blooms, animal displacement and mortality, changes in community structure and reduce recreational and aesthetic values.
- Water Quality standards have an important role in reducing the eutrophication of estuaries and coastal waters.
- The setting of standards should account for the individual characteristics of each estuary.

An analysis of the susceptibility of estuaries in the Manawatu-Wanganui Region to eutrophication

53. This analysis was undertaken with regard to the key characteristics outlined above. This used a number of tools: the NIWA New Zealand Estuary Classification database (Hume *et al.,* 2003) was used to obtain physiographic information (estuary volume, high and low tidal area, tidal prism); freshwater discharges (flows per unit time) near the terminal reaches of the rivers flowing to each estuary were obtained using NIWA Tideda software (Woods *et al.,* 2006; Henderson and Diettrich, 2007); and total nitrogen loads for terminal reaches of each river were obtained from the NIWA FINZ web interface (NIWA, 2004) using SPARROW (described above); and freshwater fraction, volume and estuary flushing time were calculated using expressions in http://oceanografia.cicese.mx/cursos/sco/chapter15.html, which describes hydro-dynamic calculations appropriate to estuaries.

54. The nutrient levels in these estuaries (for which almost no actual nutrient concentration sampling exists) were predicted using an index derived by the US National Oceanic and Atmospheric Administration (NOAA) to gauge the susceptibility of estuaries to over-enrichment (Versar, 1997; NRC, 2000). This is the ‘dissolved concentration potential’ (DCP) index (see Table 1 for derivation and results). DCP factors, together with freshwater discharge, estuarine freshwater volume and nutrient loading rate, are used to

estimate a potential nutrient level in the estuary. Systems with high DCP tend to concentrate nutrients, while those with low DCP tend to dilute or flush nutrients. This can be compared with DCP in other estuaries to gauge the relationship of the nutrient level to its trophic status (ie. non-eutrophic, moderately eutrophied, very eutrophied). NOAA categorises estuaries as having low, medium and high susceptibility to nitrogen loading, on the basis of DCP less than 100 mg/m^{-3}, 100-1000 mg/m^{-3} and greater than 1000 mg/m^{-3}, respectively. DCP index assumes the estuary is vertically un-stratified (ie. mixed) such that flushing is driven exclusively by freshwater input. It underestimates flushing where tides are primary mechanisms in controlling mixing, but this is considered minor here in these primarily river-mouth, freshwater-flushed systems (Table 1). Another qualitative decision rule-based index that has been developed by NOAA, the Estuarine Export Potential (EXP) index (NRC, 2000), allows conclusions about susceptibility to eutrophication. This could be developed for Horizons' estuaries in future.

55. Results show the extent to which estuaries in Horizons' Region are susceptible to high nutrient levels. In the major estuaries (Whanganui, Whangaehu, Rangitikei, Manawatu) and the minor estuaries, freshwater input is similar to, or exceeds, the tidal prism in controlling estuary volume (Table 1). The nutrient loads contributed by the fresh water are high, similar to the load to the Avon-Heathcote estuary, which includes Christchurch's wastewater. The potential dissolved nutrient concentrations (DCP), calculated by accounting for flushing and loading, are between 400 and 800 mgN/m^{-3}, which are considered by NOAA to be capable of rendering the estuaries 'medium' in terms of susceptibility to eutrophication. Such nutrient levels are certainly above those known to be saturating for growth of phytoplankton and nuisance macroalgae such as *Ulva* (about 70 mgN/m^{-3} or 5 micromole N: Eppley, 1979a, b; Solidoro *et al.,* 1997; de Winton *et al.,* 1988).

Are these estuaries eutrophic?

56. Although the DCP results suggest the estuaries are susceptible to eutrophication, we need to evaluate whether they actually are. The available data for major estuaries of the region do not show overt signs of eutrophication. For example, long-term records in Whanganui Estuary of dissolved oxygen (DO) at Horizons' water quality monitoring at the site 'estuary opposite the marina' shows a mean greater than 100% saturation (10 mgDO/L) and which very rarely reaches 70%. Records for the Rangitikei River upstream of the estuary are similar. However, some oxygen depression (mean of 9.5 mg/L, occasional depression to <7 mg/L) is seen in the Manawatu River at Whirokino (no records are available from within the estuary). These levels are consistent with those

measured in the lower reaches of these rivers, referred to in other evidence such as that of Dr Roger Young. The Manawatu Estuary also has a recent history of sustaining nuisance algal growth in its small intertidal area (Table 1; McBride *et al.,* 1992). These authors considered it likely that the co-occurrence of high nutrients and available intertidal substrate, which had built up in the Manawatu Estuary in the previous decade with a change in location of the estuary mouth (Woods and Kennedy, 2008), underlay the formation of these dense macroalgal beds (*Enteromorpha, Chondria* and *Gracilaria*). Nutrient levels in this estuary were shown by these authors to be only slightly lower than those recorded in wastewater-affected Manukau Harbour and Avon-Heathcote Estuary. Other than these reports, there is no other in-estuary monitoring on which to evaluate the trophic status of Horizons' Region estuaries. However, other than that described above for Manawatu Estuary, there are no reports of macroalgal buildup in estuaries, such as seen in Avon-Heathcote Estuary (Fig. 1).

57. It would appear that the reason extensive macroalgae, low DO and other eutrophic symptoms are generally not present in these estuaries is the due to their physiography. They generally have no or very little intertidal area capable of supporting attached macroalgae (Table 1) and they are turbid (eg. 'black disc' mean for Whanganui at Estuary site was only 0.54 m). They are river-dominated, with frequent low salinity and are rapidly flushed (flushing times generally < 0.5 day: Table 1) such that phytoplankton blooms do not form. These estuaries essentially act as 'pipelines to the sea' for their high dissolved and particulate nutrient loads, with negligible biological processing by water column or benthic algae during transit.

58. In addition to elevated nutrients, necessary conditions for macroalgal bloom formation are the availability of substrate, appropriate light levels and possibly high salinity (these conditions may be correlated where intertidal areas are built up that are only inundated at high tide). Such conditions are clearly achieved within the Avon-Heathcote Estuary and other New Zealand mudflat-dominated estuaries with macroalgal bloom problems. These attached algae are bathed in relatively high salinity waters and often exposed to high light levels, albeit with only 'moderate' DCP (Table 1). The fact that the Avon-Heathcote Estuary is predicted to have only moderate DCP, yet is highly eutrophic, indicates the DCP method has an inconsistency in successfully predicting eutrophy shallow, macrophyte-dominated estuaries *cf* deeper plankton-dominated estuaries, a feature of the index which has been noted previously (NRC, 2000).

59. It is clear that the loadings to estuaries in Horizons' Region are generating potentially high estuarine nutrient levels and it is likely that it is only their physiography (rapid

flushing, turbidity, lack of available substrate) which is preventing the evolution of eutrophic conditions. This raises the point that these river-estuary systems also transport sediment loads that are high on a New Zealand-wide basis (Hicks and Shankar, 2003) – similar in absolute magnitude to the large rivers of Canterbury and the South Island West Coast. Should geomorphic conditions change, allowing this transport to create intertidal habitat (which appears to have happened in Manawatu Estuary), it is possible that symptoms of macroalgal eutrophication will appear more commonly.

Water quality conditions in the seawater management area

60. It is difficult to make conclusions about the significance of these high nutrient loads once they have entered the energetic Seawater Management Area on the Manawatu-Wanganui coastline. The water quality sampling at a number of coastal sites (K. McArthur, Horizons Regional Council *pers. comm*., March 2009) from Kai Iwi Beach to Waitarere Beach (including Castlecliff, Himatangi and Foxton beaches) do show considerably elevated levels (200-600 mg/m^3 total nitrogen 90th percentile ranges) *cf* 'normal' coastal site levels (generally less than 10-30 mg/m^3) such as found off Lyttleton Heads, Christchurch, or in Tamaki Strait, Auckland (*pers. obs*.; Zeldis *et al.,* 2001). Horizons' Seawater Coastal Marine Area (CMA) sampling sites are adjacent to their estuaries and it is likely they are reflecting their high estuarine nutrient loads. However, without direct surveying it is unknown if they are generating elevated phytoplankton or attached algal proliferations in adjacent shore areas over significant spatial extents. It is noted that the recent open coast CMA sampling has not included co-occurring measurement of salinity (conductivity) and nitrogen, inclusion of which would help describe freshwater influence on limiting nutrient level. This could help separate 'event-driven' (ie. riverine), from diffuse loading (ie. from coastal sands areas).

61. It would be beneficial to examine coastal loading impacts with ground surveys of these areas, to test for presence of eutrophic symptoms (macroalgal growth, deoxygenation). A potential cost-effective tool for assessing the impacts of the coastal plumes emanating from the major estuaries would be to exploit ocean-colour remote sensing, as is currently being developed to investigate river plume dynamics and impacts in the Canterbury Region (Schwarz *et al.* 2009).

Key Points

- Nutrient loads to the major estuaries are elevated and these estuaries have been determined to be medium in terms of their susceptibility to eutrophication.
- The eutrophication potential of the major estuaries is reduced by their physiography, having low retention times and little available substrate for macroalgal attachment.
- Eutrophication effects are more likely if physiography and sediment transport regimes change in future
- Seawater Management Zones exhibit elevated nutrient loads, likely to be predominantly from riverine inputs.
- More data is required and eutrophication effects are largely unknown.

Implications for defining nutrient water quality standards in Horizons' estuary management sub-zones and seawater management zone

62. For estuaries, it is advised that nutrient levels be held at or below their present levels, as they are already high and, with changes in estuarine physiography (increased intertidal area, decreases in turbidity), could easily generate eutrophic problems. This applies primarily for nitrogen, because it is the key limiting nutrient in these systems (see point 4), but applies also to phosphorus, which is also likely to be present at high concentrations. It is noted that the proposed standards in Schedule H for soluble inorganic nitrogen (SIN: 444 mg/m^3 in Manawatu, 110-167 mg/m^3 in other Horizons estuaries) are similar to, or lower than, those predicted in the DCP analysis (Table 1) for total N. This is understandable given that SIN does not include organic or particulate N forms, which total N does. However, inorganic forms are generally major components of heavily nutrient-loaded rivers in New Zealand (eg. in the heavily N-loaded Waihou and Piako rivers, SIN contributes about half the total N load: Zeldis, 2008). Thus, the proposed 167 mg/m^3 standard probably reflects current average SIN levels or a reduction in them.

63. The standard for Manawatu Estuary should not be set higher than in the other estuaries, as this estuary has already shown eutrophic symptoms (McBride *et al.,* 1992) and considering that it has high value as a Ramsar site for wading birds (Melville and Battley, 2006). It must also be noted that the DCP method is only approximate and more accurate determinations of estuarine nutrient levels would only be obtained with direct estuarine sampling. The same recommendation applies for the Seawater zones. For both management areas, the SIN standard should be subject to modification based on surveys to check for signs of eutrophy, as described above.

64. It is noted that these standards are much higher than the ANZECC (2000) guideline trigger levels (about 30 mg/m^3 soluble inorganic nitrogen) for 'slightly disturbed estuarine water' (Bolton-Ritchie and Main, 2005). These guidelines are based on oligotrophic (low-nutrient) waters of South-east Australia (as of 2005 no nutrient trigger levels had been developed for New Zealand waters: Bolton-Ritchie and Main, 2005). Another standard, discussed by Knox and Kilner (1973) in their study of the Avon-Heathcote Estuary and developed for reversing eutrophication in the Potomac Estuary (US), recommended much higher criteria (300-500 mg/m^3 soluble inorganic nitrogen). The standards proposed for most estuaries in Schedule H of the Proposed One Plan are somewhat lower than this (110-167 mg/m^3), but the proposed standards are considered reasonable, given the apparent susceptibility to eutrophy in Horizons' estuaries upon changes in geomorphology, such as has occurred in the Manawatu Estuary.

- I recommend the 444 mg/m^3 soluble inorganic nitrogen (SIN) standard for the Manawatu Estuary sub-zone is reduced to 167 mg/m^3.
- All other nutrient standards should remain as proposed in Schedule H.

Other standards

65. Soluble inorganic nitrogen (SIN) is largely composed of two N forms in estuaries, being nitrate (NO_3^-) and ammonia ion (NH_4^+ - usually called ammonium). However, relatively low concentrations of unionised ammonia (NH_3) can occur under conditions of high ammonium concentration, and it is toxic to marine life. The ANZECC (2000) guidelines give trigger levels (for continuous exposure) for ammonium which should be avoided to prevent toxicity resulting from accompanying ammonia: (500, 910, 1200, 1700 mg/m^3 respectively) that provide for 99, 95, 90 and 80 percent protection from ammonia toxicity for species in marine water (there are no values given for estuarine water: Bolton-Ritchie and Main, 2005).

66. I support the limit of 400 mg/m^3 ammoniacal nitrogen applied in Schedule H of the Proposed One Plan to provide for protection of estuarine species. It is likely that this is currently met in existing water quality of estuaries in Horizons' Region (based on the DCP results), although this is uncertain because ammonium (or most other water quality parameters) has not been measured. This trigger level would be met by default with a SIN trigger level of 110-167 mg/m^3. The ammonium trigger levels are to some extent pH, temperature and salinity dependent (Bolton-Ritchie and Main, 2005), so it is

recommended that those variables be routinely measured at all future water quality sampling which includes nitrogen and phosphorus.

67. Standards for other toxins have been set at the 95% protection level from the ANZECC guidelines. I support retaining these standards in both Estuary Sub-zones and the Seawater Management Zone.

68. Standards have also been set for pH, temp, BOD_5, and Particulate Organic Matter (POM). pH and temperature are unlikely to be negatively affected by activities in the coastal environment due to buffering in seawater, so standards for these parameters are considered unnecessary for Schedule H. Likewise, the BOD_5 standards should be adequately covered by the dissolved oxygen saturation standards (discussed below) and particulate organic matter (POM) is generally only relevant to benthic invertebrates in hard-bottomed river and stream habitats (see the evidence of Dr Quinn). These standards should also be removed from Schedule H.

69. Dissolved oxygen saturation standards proposed in the draft Schedule H are 60% or 70%, depending on the estuary management sub-zone. These correspond to DO concentrations of 5.5 and 7.5 mg/L at the summer trigger level (19^{o} C) in estuarine temperature (Horizons Regional Council, 2005; http://www.ciese.org). It is noted that the commonly used DO level of 2 mg/L to designate hypoxia found in much of the literature (eg. http://www.cop.noaa.gov/stressors/pollution/current/chrp.html) is not considered tenable as a safe trigger level for avoidance of hypoxic impacts (Vaquer-Sunyer and Duarte, 2008). A level of 4.6 mg/L is recommended by those authors as ‘a precautionary limit to avoid catastrophic mortality events, except for the most sensitive (eg. crab) species, and effectively preserve biodiversity’. Remaining well clear of this limit is advised and for this reason it is recommended that the limit for those estuaries notified for 60% DO limit on saturation be increased to 70%. The proposed minimum of 90% DO saturation in the Seawater Management Zone is satisfactory. Lower river DO standards should be set with these objectives in mind.

- I recommend the 400 mg/m^3 standard for ammoniacal nitrogen is retained in the Estuary Sub-zones.
- I recommend retaining the toxicity standards as proposed in Schedule H.
- I recommend standards for pH, temperature, BOD_5, and POM are removed from Schedule H.
- I recommend minimum dissolved oxygen saturation in Estuary Sub-zones currently proposed as 60% is raised to a minimum of 70%.
- I recommend retaining the Seawater minimum dissolved oxygen standard at 90% of saturation.

70. Microbiological indices proposed in Schedule H do not include enterococci for the Estuary Sub-zones. Enterococci is the appropriate indicator to use for faecal contamination in seawater (Horizons Regional Council, 2005; Bolton Ritchie, 2008), whereas *E. coli* is appropriate for freshwater. An Alert trigger level of 140 enterococci cells/100mL is recommended by MfE/MoH Recreational Water Quality Guidelines (2003 - as cited in Bolton-Ritchie, 2008) for safe contact recreation and should be carried out in waters with conductivity > 200 µs/cm (Horizons Regional Council, 2005). The monitoring should be interpreted in context of the grading procedures outlined in the Guidelines. These include: the Sanitary Inspection Category (SIC), which generates a measure of the susceptibility of a water body to faecal contamination; historical microbiological results; and a Microbiological Assessment Category (MAC), which provides a measurement of the actual water quality over time. This estuarine sampling should be included in light of generally poor bacteriological water quality in the Region's rivers (Horizons Regional Council, 2005) and, as noted, specifically for Manawatu Estuary by McBride *et al*. (1992). It is likely that efforts to improve bacteriological water quality in the rivers will improve overall water quality (including contact recreation and nutrients) in the estuaries.

71. Periphyton standards as applied to the freshwater systems are not appropriate in the estuarine/coastal context and marine filamentous algae, macroalgae, and phytoplankton should be considered instead. It is suggested that monitoring be put in place to detect change in filamentous and macroalgal cover, which at present appears to be low in most places. A focus on Manawatu Estuary in this regard is recommended, given the importance of the estuary as a Ramsar site and its apparent geomorphic and macroalgal changes noted in McBride *et al.* (1992: see point 17, above). There is presently almost no algal cover for most of the estuaries. If they suddenly start producing macroalgae, this should be an alarm flag. Therefore it is recommended that a standard of no more

than 20% of randomly selected but previously uncovered shore area by macroalgae be set as a standard for an alert. Given the high concentrations of nutrients in coastal sampling to date and anecdotal observations of 'surf algae' in the Region (K. McArthur, Horizons Regional Council *pers. comm.* May 2009), it is recommended that sampling for phytoplankton be incorporated in the estuarine mouths and adjacent coastal areas. These measures could be made in conjunction with New Zealand Food Safety Authority's harmful algal bloom sampling (New Zealand Food Safety Authority, 2006) in the case of toxic bloom monitoring. If deemed necessary, monitoring and compliance for cyanobacteria could be initiated following protocols recommended in MfE (2009).

72. The proposed chlorophyll *a* concentration standard of 1 mg/m^3 in the Seawater Management Zone is too low for an appropriate phytoplankton threshold. I recommend that a higher threshold for chlorophyll *a* $/m^3$ concentration is determined for the Seawater Management Zone.

73. No visual clarity standards appear to have been enumerated for coastal waters and estuaries in New Zealand. A default approach would be to propose for coastal waters visual black disk clarity of 1.6 m for bathing safety and no more than 20% change – consistent with Horizons' proposed standards for freshwaters. However, existing black disk readings for the Horizons' Region estuaries show that they are far more turbid than this (see point 18 above), which probably reflects the state of the lower major rivers (Horizons Regional Council, 2005) plus the likelihood that estuaries may experience higher turbidity naturally due to erosion, tidal re-suspension, flocculation etc. It may be most appropriate to monitor clarity to detect change, which may accrue with river water quality changes.

Recommendations

- I recommend the enterococci standards as proposed for the Seawater Management Zone in Schedule H are retained.
- I recommend that standards for faecal indicator bacteria are applied to all Estuarine Sub-zones as follows: when water in Estuary Sub-zones has a conductivity > 200 µs/cm, the enteroccoci standards for the Seawater Management Zones will also apply to Estuarine Sub-zones; when conductivity < 200 µs/cm, the *E. coli* standards for rivers and streams shall apply.
- I recommend that standards for periphyton cover and chlorophyll *a* are removed from all Estuary Sub-zones.
- I recommend a standard be added to the Estuarine Sub-zones ensuring that macroalgal cover shall not exceed 20% of shore surface area.
- I recommend the chlorophyll *a* standard for Seawater Management Zones is raised.
- I recommend the removal of turbidity standard proposed in Schedule H for both Seawater Management Zone and Estuary Sub-zones.
- I support the recommendation of Dr Davies-Colley for a minimum horizontal visibility standard of 1.6 m (black disc measurement) to protect contact recreation and no more than 20% change in horizontal visibility for the Seawater Management Zone.
- I support the recommendation of Dr Davies-Colley for a 20% change in horizontal visibility limit to apply to Estuary Sub-zones, but I do not support a minimum horizontal visibility standard as estuaries are unlikely to meet this due to physical factors.
- I also support the recommendations of Dr Davies-Colley for no more than a 10% change in euphotic depth for estuarine and coastal waters.

4. REFERENCES

*Note – those references in **bold** type I consider to be **key references** that may be useful to consult to amplify points made in my evidence. Other references are listed – and cited in evidence – mainly for scholarly 'authority'.*

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Figure 1. View of the Avon-Heathcote Estuary, Christchurch

This shows the excessive macroalgal growth of *Ulva* (sea lettuce), characteristic of eutrophic conditions in mudflat estuaries in New Zealand and overseas.

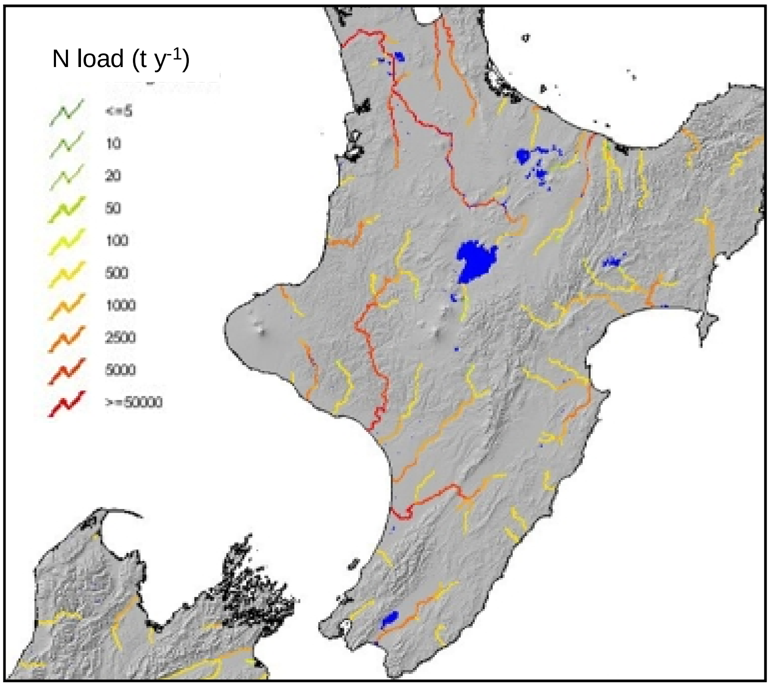

Figure 2. Output from NIWA Freshwater Information New Zealand (FINZ) website

From http://finz.niwa.co.nz/NewZealand/viewer.htm showing annual mean total nitrogen loading in major North Island rivers. Note high loading in Whanganui, Whangaehu, Rangitikei and Manawatu rivers, comparable to Waikato River and Waihou/Piako system (Firth of Thames).

Table 1. Freshwater, tidal and nutrient fluxes for Manawatu-Wanganui estuaries, including Dissolved Concentration Potential (DCP)

	FW discharge	Daily FW discharge	FW discharge per tide	Estuary volume	Tidal prism	FW volume	FW fraction	Total N load	DCP (total N)	Flushing time	High tide area	Intertidal area
Estuary	(m^3/s)	Q_f (10^6 m^3/d)	V_R (10^6 m^3)	V_t (10^6 m^3)	V_T (10^6 m^3)	V_f (m^3)	f*	L (tN/y)	(mg/m^3)	t_F (d)	(km^2)	(km^2)
Whanganui	225	19.4	10.0	7.7	8.4	4.2	0.54	5800	400	0.21	3.22	0.00
Whangaehu	47	4.1	2.1	2.0	1.1	1.3	0.65	900	400	0.32	0.43	0.00
Turakina	8	0.7	0.4	1.2	0.3	0.7	0.57	300	700	0.93	0.43	0.14
Rangitikei	76	6.6	3.4	1.7	0.9	1.3	0.78	1300	400	0.20	0.39	0.01
Manawatu	124	10.7	5.5	9.1	4.9	4.8	0.53	5800	800	0.45	2.13	0.04
Ohau	7	0.6	0.3	0.9	0.6	0.3	0.34	200	300	0.50	0.28	0.00
Waikawa	2	0.2	0.1	0.2	0.2	0.1	0.38	100	500	0.42	0.11	0.06
Owahanga	8	0.7	0.4	1.4	0.8	0.4	0.31	200	300	0.62	0.59	0.00
Akitio	11	1.0	0.5	0.6	0.4	0.4	0.58	300	500	0.38	0.26	0.00
Avon-Heath	5	0.4	0.2	13.9	8.9	0.3	0.02	2300	300	0.79	7.47	4.96
Physiographic data unavailable for following small estuaries												
Kai Iwi	2							100				
Hokio	1							100				
Wainui	2							100				

DCP was calculated as: $DCP = L\ (V_f/Q_f)\ (1/V_t)$ where L is total nitrogen loading, V_f is freshwater volume of the estuary during spring high tide (calculated as the freshwater fraction f^* times the estuary volume, V_t, at spring high tide: Versar, 1997) and Q_f is mean river discharge. $f^* = V_R / (V_T + V_R)$ where V_R is the freshwater discharge over a tidal cycle (12.4 h) and V_T is the tidal prism at spring tide. Total nitrogen loads (L) were obtained for terminal reaches of each river using the FINZ web interface (NIWA, 2004) which uses Spatially Referenced Regressions on Watersheds (SPARROW) to accumulate N loads down-catchment based on catchment characteristics, land use and in-river parameters. Freshwater discharge (cumecs, Q_f, V_R) was derived from gaugings near the terminal reaches of the rivers flowing to each estuary using NIWA Tideda software (Woods *et al.,* 2006; Henderson and Diettrich, 2007). V_T and V_t were obtained from the NIWA NZ Estuarine Classification Database (Hume *et al.,* 2003). The estuarine flushing time (t_f) is the time to replace the estuarine water mass using tidal and freshwater flushing. Also given are the estuary surface area at high tide and the intertidal area (Hume *et al.,* 2003). Physiographic data were unavailable for the indicated small estuaries, but discharge and N load data are presented.