BEFORE THE ENVIRONMENT COURT

Under: the Resource Management Act 1991 (“the Act”)

In the matter of: appeals under clause 14 of the First Schedule to the Act concerning the Proposed One Plan for the Manawatu-Whanganui Region and the topic of Surface Water Quality

Between: **MINISTER OF CONSERVATION**
ENV-2010-WGL-000150

FEDERATED FARMERS OF NEW ZEALAND
ENV-2010-WLG-000148

MR ANDREW DAY
ENV-2010-WLG-000158

HORTICULTURE NEW ZEALAND
ENV-2010-WLG-000155

WELLINGTON FISH & GAME COUNCIL
ENV-2010-WLG-000157

Appellants

And: **MANAWATU-WHANGANUI REGIONAL COUNCIL**
Respondent

STATEMENT OF EVIDENCE OF DAVID JOHN KELLY ON BEHALF OF THE MINISTER OF CONSERVATION

Dated: 15 March February 2012

Minister of Conservation
c/-P O Box 462 Tel +64 6 759 0205
55 a Rimu Street Fax +64 6 759 0351
New Plymouth
Solicitor acting: Sarah Ongley

STATEMENT OF EVIDENCE OF DAVID JOHN KELLY

1. My full name is David John Kelly.

2. I have the following qualifications: PhD (University of Alberta, Canada), BSc (University of Victoria, British Columbia, Canada). I am a member of the New Zealand Freshwater Sciences Society (since 2001), the North American Benthological Society (since 1996), and the International Society of Theoretical Limnology (since 2007).

3. From 2006 until February 2012 I worked as a freshwater scientific advisor with the Department of Conservation (DOC), Research and Development Group, Freshwater Section. In March 2012 I took up a position as a senior scientist with the Cawthron Institute in Nelson in their Coastal and Freshwater Section. Prior to working at DOC, I worked for the National Institute of Water and Atmospheric Research (NIWA) in Christchurch as a freshwater scientist (2001-2006), and before this I obtained my Doctor of Philosophy degree in the School of Biological Sciences at the University of Alberta, Canada (2001), in the field of freshwater ecology focusing on the management of forestry practices in rivers in British Columbia.

4. In my role with DOC I was the principal scientist responsible for managing its research on lake ecosystems, and I was one of three scientists who directed the technical work in DOC's National Heritage Management Strategy (NHMS) that prioritises the conservation values of freshwater environments across New Zealand for DOC. I recently (2007-2011) led a Cross Departmental Research Pool Project funded by the Ministry of Science and Innovation on quantifying relationships between catchment pressures and the ecological integrity of rivers and lakes, of which the lakes portion of the project specifically focused on lowland coastal lakes and lagoons. I was regularly asked to provide advice to central and regional government initiatives on lake monitoring and management. I presently sit on technical advisory groups and the steering panel for national monitoring and reporting for National Environmental Monitoring and Reporting as part of the Fresh Start Water Initiatives led by the Ministry for the Environment. I have been involved in number of projects working the central government and regional councils to manage nutrient

loading into lakes, including Lake Brunner, Te Waihora, Lake Forsythe, Waituna lagoon, and the Ashburton Lakes.

5. I am familiar with the Proposed One Plan (the POP) and several of the freshwater catchments to which these proceedings relate.

6. I have read the Environment Court's Code of Conduct for Expert Witnesses 2011, and I agree to comply with it. I confirm that the issues addressed in this brief of evidence are within my area of expertise. I have not omitted to consider material facts known to me that might alter or detract from the opinions expressed. I have specified where my opinion is based on limited or partial information and identified any assumptions I have made in forming my opinions.

7. I have read the following evidence presented by other experts on behalf of Horizons relevant to my area of expertise, including:
    i. Mr Max Gibbs (NIWA) (Section 42A Report)
    ii. Ms Kate McArthur (Horizons Regional Council) (Section 42A Report)
    iii. Dr Jonathon Roygard (Horizons Regional Council) (Section 42A Report)
    iv. Mr Barry Gilliland (Horizons Regional Council) (Section 42A Report)
    v. McArthur et al. End of Hearing Report particularly Appendix 3 (setting out expert agreement on water quality standards for lakes) and Appendix 5 (setting out expert agreement on environmental benefits of proposed Rule 13-1 for lakes)
    vi. Roygard et al, 2012. Joint technical expert statement on the topic of surface water quality – non-point sources discharges. (includes a short section about Manawatu lakes)
    vii. Associate Professor Russell Death 2012 statement of evidence (Wellington Fish and Game Council)
    viii. Dr Olivier Ausseil statement of evidence (Minister of Conservation and Wellington Fish and Game Council)

8. I have also read Gibbs, 2011 Lake Horowhenua Review: Assessment of opportunities to address water quality issues in Lake Horowhenua. Report prepared for Horizons by NIWA.

9. I am authorised to present evidence on behalf of the Minister of Conservation in relation to the POP in my area of expertise relating to coastal dune lakes and management of landuse activities within their catchments.

10. In particular, my evidence relates to the Minister of Conservation’s appeal in relation to three water management zones (four water management subzones): Horowhenua (subzones Hoki 1a and Hoki_1b); Kaitoke Lakes (West_4) which includes the Kaitoke, Wiritoa, Kohata, Pauri lakes and the Marangi bush wetland; and South Whanganui lakes (West_5) which includes lakes Bernard, Koitiata, Dudding, Heaton, Alice, Rhodes and Herbert.

10. My evidence is set out as follows:

PART A - Dune lakes and their catchments within the Manawatu-Whanganui Region

PART B - Use of predicted relationships between catchment landuse and the condition of coastal dune lakes to inform management decisions

PART C - Management activities to maintain or improve water quality of dune lakes in the Manawatu-Whanganui Region

LAKES AND THEIR CATCHMENTS WITHIN THE MANAWATU-WHANGANUI REGION

11. The Freshwater Ecosystems of New Zealand database (FENZ) classifies 3821 lakes that are greater than one hectare in area occurring across the North and South Islands and some of the smaller outlying islands (e.g., Stewart and D'Urville Islands) (Leathwick et al. 2010). The database was developed by DOC in conjunction with NIWA with the aim of classifying all lakes in terms of their geomorphic, physical, and biological characteristics for systematic management of lakes.

12. FENZ shows there are 226 lakes contained within the Horizons Regional Council boundaries. This includes lakes from seven geomorphic formation types: volcanic, riverine, landslide, wetland-formed, beach-lagoons, dune lakes, and man-made reservoirs. These geoformation attributes of lakes are linked to functional and landscape attributes that influence ecological processes (e.g., elevation, connectivity to rivers and the coastal zone, lake basin morphometry, and climatic patterns), thus geoformation is often used a surrogate feature for classifying lakes (e.g. Irwin 1975, Livingston et al. 1986).

13. The lakes I focus on in this evidence are all dune lakes. Dune lakes are generally formed by the blockage of stream valleys and depressions formed by blown sand. As Mr Gibbs has explained in detail in his Section 42A Report the formation of these lakes occur predominantly in two ways. Firstly, and more commonly is when wind blown materials (generally sand) deposit in the basin of an existing stream draining to the sea, thereby flooding an upstream area as the outflow is blocked; secondly, when an unconnected (i.e. no stream inflow) basin floods due to the reduction in subsurface drainage caused by the deposition of less permeable soil materials (e.g., clay, silt) within a depression, which generally occurs during episodic events such as large floods.

14. The lowland coastal portions of the Manawatu-Whanganui region contain a relatively large number of dune lakes, comprising 57 of the 330 that occur nationally. Eighteen of these lakes are within the four water management

subzones (West_4: 7 lakes, West_5: 10 lakes, Hoki_1a&1b: 1 lake) of the POP.

15. The largest of the region's dune lakes is Lake Horowhenua, which is 304 hectares in area and the largest dune lake in the country. Most of the lakes in the region are considerably smaller, typically less than 25 hectares (average 14.6 ha), with the exception of Lake Papaitonga (51 ha) immediately south of Horowhenua. Most of the lakes are clustered within the landscape occurring along the margins of dune swales where river drainage has been blocked by dune formation.

Biodiversity values of dune lakes

16. On an international basis, dune lakes constitute a rare environment class with the only known occurrences in New Zealand, Australia, Madagascar, and the South-Eastern coast of the USA. The greatest abundance occurs along the West Coast of the North Island of New Zealand, particularly through Northland but extending southward through to the Wellington region with a cluster of lakes in the Manawatu-Whanganui region. There are also smaller pockets of dune lakes along the West Coast of the South Island extending as far as Southland, but far less numerous than in the North Island.

17. Biological communities of dune lakes can be distinctive owing to their historical isolation and lack of downstream seaward connectivity (Ball, Pohe and Winterbourn 2009). For example several of the Northland dune lakes contain genetically distinctive forms of dune lake galaxiias and dwarf inanga derived from migratory ancestral inanga which would have occupied the coastal stream basins prior to being isolated by dune movement (Rowe and Chisnall 1997). Seepage outlets and a lack of direct sea connection also means that many dune lakes do not contain diadromous predatory species such as shortfin eels, which tends to enhance populations of threatened galaxids. Although I am not aware of genetically distinct galaxid species within the dune lakes of the Manawatu-Whanaganui region, several of the lakes do contain other threatened species such as migratory longfin eels (see Table 1 below) (Allibone et al. 2010).

18. In relatively unmodified catchments (i.e., reference condition), dune lakes typically have high ecological and human recreational values (Drake et al. 2009). They are typically clear, and have intermediate concentrations of dissolved nutrients, some degree of nutrient inputs from ground waters in near coastal areas. Submerged and emergent plant communities are usually present and provide habitat for diverse invertebrate fauna. Fish communities can vary quite substantially between lakes depending on their historical connectivity to upstream and downstream stream drainage networks. Lakes can range from having no fish species, to those having populations of diadromous species (e.g., shortfin and longfin eels, common bully, smelt, inanga, banded kokopu) where connections to the sea are either present or intermittent. The low number of fish species that occur in some dune lakes can be viewed as an indication of lower ecological value. However, I believe this not to be the case as dune lakes naturally contain unique simple foodwebs with species sensitive to the presence of migratory top predators such as eels and other invasive species.

19. The known biodiversity values of the various lake catchments are summarised in Table 1. The information is taken from Ms McArthur's section 42A Report and DOC Conservancy Office data sources. Biodiversity values include the presence of remnant populations of regionally rare and threatened native fish species such as banded kokopu and giant kokopu in the two inflowing tributary streams of Lake Horowhenua as noted by Ms McArthur in her section 42A Report. Ms McArthur also notes that water body values of both the Southern Whanganui Lakes and Kaitoke Lakes water management subzones include inanga spawning and whitebait migration. Coastal tributaries along the Foxton ecological district are particularly significant for inanga spawning and those that lead to dune lakes provide migrating whitebait (which include threatened species such as inanga, giant kokopu and koaro) access to important habitat in the form of the dune lake.

20. Kakahi are currently classified as threatened species in gradual decline (Hitchmough, 2007). While Kakahi (freshwater mussels) have been confirmed from three of Horizons lakes (Pauri, Dudding and Horowhenua), (L. Brown, pers comm.) it is highly likely that other lakes provide suitable habitat**.**

Longfin eels and inanga have also recently been classified as threatened species in gradual decline (Allibone et al 2010).

Table 1. An overview of the biodiversity values of some of the dune lakes in the Manawatu-Whanganui region according to their water management subzones. Source from McArthur Section 42A Report and DOC regional office data sources

Subzone	Lake name	Lake Area (HA)	Catchment Area (HA)	Biodiversity values
Kaitoke Lakes West_4	Wiritoa	21.8	696	• Known populations of kakahi (freshwater mussel) in Lake Pauri (L. Brown, pers com) and likely to be in other lakes. • Ms McArthur (S42A report) lists the water body values for this water management subzone as including inanga spawning and whitebait migration. • Historic cultural and commercial eel fishery. • Rare and threatened plants recorded, most being turf plants (J. Campbell, pers com). • The Kaitoke stream (outflow from Kaitoke lake) is probably the most highly whitebaited stream (aside from the mainstem of the Whanganui River) in the Whanganui region (J. Campbell, pers com). • Two nationally threatened species: the New Zealand dabchick (weweia) and the Australasian bittern (matuku-hurepo) are found here (J. Campbell, pers com). • Lake Kaitoke has a wildlife refuge status.
	Pauri	19.2	383	
	Kaitoke	25.3	3265	
	Kohata	5.2	84	
	3 unnamed lakes			
Southern Whanganui Lakes (West_5)	Bernard	8.0	734	• Known populations of kakahi (freshwater mussel) in Lake Dudding (L. Brown, pers com) and likely to be in other lakes. • Ms McArthur (S42A report) lists the water body values for this water management subzone as including inanga spawning, whitebait migration and includes sites of significance – aquatic (banded kokopu). • Long fin eel (now listed as being in gradual decline: Allibone et al 2010) found in both Koitata stream and Lake Koitiata (New Zealand Freshwater Fish Database (NZFFD)). • Rare plant assemblages exist around Lake Alice in the largest area of dune forest north of the Manawautu river in the Foxton ecological district (J. Campbell, pers com).
	Koitiata	9.6	1406	
	Dudding	7.8	184	
	Heaton	14.4	956	
	William	6.8	71	
	Alice	11.9	238	
	Hebert	4.7	375	
	3 unnamed lakes			

Hoki 1a, 1b	Horowhenua	304.0	6253	• Inflowing streams hold remnant populations of banded and giant kokopu (NZFFD). • Ms McArthur (S42A report) lists the water body values for this water management subzone as including inanga spawning, whitebait migration and includes sites of significance – aquatic (giant kokopu). • Known populations of kakahi (freshwater mussel) (L. Brown, pers comm.) • Historic cultural and commercial eel fishery. • Longfinned eels recorded from Hokio stream (outlet of Lake Horowhenua) (NZFFD)

State of dune lake catchments regionally and nationally – Catchment condition

21. Due largely to their location in the landscape, catchments of most dune lakes in New Zealand have been subject to high degrees of human modification such as forest clearance, agricultural development, and urbanisation. To show this I used the FENZ database, which contains data fields for catchment attributes such as native vegetation cover, pastoral agriculture cover, urban impervious area, nitrogen loading, and the known records of exotic species (Leathwick et al 2010), to conduct a national scale analysis of all lakes (> 1ha in area) with the catchment analysis sorted by lake geomorphic formation type to compare the degree of catchment modification among lake types.

22. I then looked specifically at all dune lakes nationally (n=330), and those contained only within the Manawatu-Whanganui Region. These analyses included 3595 lake catchments of eight lake geoformation types (dune, beach-formed, riverine, swamp-formed, landslide, glacial, volcanic, and man-made), according to those reported in Livingston et al. (1986) and Irwin (1975). A small number of lakes (51 tectonic and geothermal lakes) were omitted from the analysis due to their low prevalence.

23. Results of the lake catchment analysis are contained below in Figures 1(a)-(c). The analysis shows that a national scale, catchments of dune lakes have been subject to more modification in relation to indigenous forest clearance and pastoral agriculture development than other lake types. On average, nationally dune lake catchments contained only 27% of their areas covered in

native vegetation, which was significantly lower than all other lake types with the exception of man-made lakes (ANOVA, $P<0.001$, Bonferroni test) (Figure 1a). Furthermore, 47% of the catchment of an average dune lake has been converted to pastoral agriculture land use, which is a significantly higher proportion compared to glacial, volcanic, and landslide lake types (ANOVA, $P<0.001$, Bonferroni test) (Figure 1b). Nationwide, catchment pastoral agriculture cover for dune lakes was similar to other predominantly lowland lake classes such as coastal lagoons, riverine lakes, and swamp-formed lakes (Figure 1b).

24. For the dune lake catchments within the Manawatu-Whanganui region, this trend was even more pronounced, with on average only 11% of the catchment areas in native vegetation cover (Figure 1a), and on average 68% of the catchment converted to pastoral agriculture land use (Figure 1b).

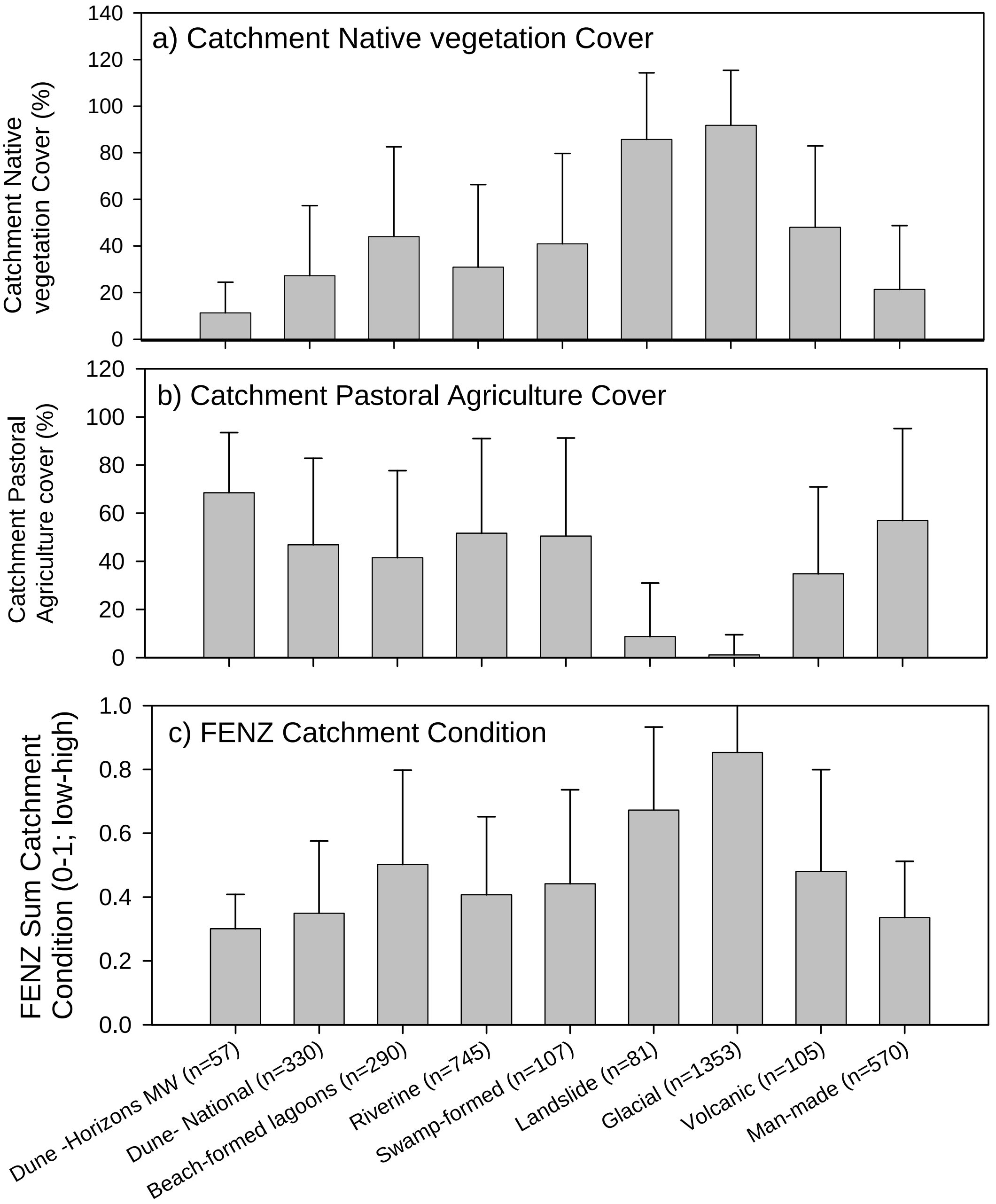

Figure 1. Average (+ Standard Deviation) FENZ lake catchment scores of 8 lake types in New Zealand, for a) native vegetation cover, b) pastoral agriculture cover, and c) Catchment condition index. Note the dune lake category is broken into averages both nationally and for the Manawatu-Whanganui region.

25. Ms McArthur’s section 42A Report highlighted the proportion of landuses within each of the relevant water management subzones subject to appeal.

26. Her analysis also highlights the extremely small amount of native vegetation cover remaining in these areas and the dominance of pastoral agriculture cover (and urban impervious catchment cover in the case of Lake Horowhenua). For example, in the Horowhenua water management zone, built-up (urban) land use occupies 12% of the catchment, pastoral agricultural cover (sheep and beef, dairy, cropping and horticulture) occupies 75.5% with native cover occupying only 3.5% of the catchment. The Kaitoke Lakes management zone (West_4) was made up of 70% pastoral agriculture cover (sheep and beef, dairying and cropping), 25% exotic cover and only 5% native vegetation cover. The Southern Whanganui Lakes (West_5) had only 1% in native cover.

27. Thus, pastoral agriculture cover (and urban in the case of Horowhenua) within the four water management subzones all exceeded both the regional and national averages for all lake types, indicating that these subzones occur within highly modified landscapes. Ms McArthur’s analysis is consistent with my analysis of the FENZ database described in paragraphs 21 to 23 above.

28. The FENZ database also computes an overall catchment condition index (Figure 1c) that has been calibrated by a number of lake experts against in-lake condition metrics where data was available (DeWinton, Kelly and Leathwick 2008). The scores take into account the previously discussed catchment cover characteristics, predicted total nitrogen loading using the CLUES national model (model discussed in detail in paragraph 37 of my evidence), and the presence of human made barriers to diadromous fish migration such as dams and tidal gates. These factors were weighted in the calculation of the condition index based on their expected relationship with in-lake condition, and scores normalised between 0-1 with zero being highly degraded and 1 being completely unmodified.

29. Based on these summed pressure scores plotted for the eight lake categories (Figure 1c), dune lakes along with man-made lakes were the most degraded lake types nationally in terms of their overall catchment condition, and were significantly more degraded than all other lake classes (ANOVA, $P<0.001$, Bonferroni test).

30. Within the Manawatu-Whanganui region, catchment condition indexes for all dune lakes were lower than the national average for dune lakes, with the average score for the region of 0.30 compared with 0.35 nationally. West_4 and West_5 had an average condition index similar to that of the regional average of 0.3 (West_4 0.29, West_5 0.31). Lake Horowhenua had a lower condition index of 0.23.

Invasive Species

31. The FENZ database contains information on the known occurrence of exotic fish and aquatic plant species, taken from the New Zealand Freshwater Fisheries Database (NZFFB) and the Freshwater Biodiversity Information System (FBIS), both maintained by NIWA. The information is based on known occurrences from field observations and thus is limited in terms of the number of lakes for which information is available. As an indication of coverage, approximately 650 lakes presently have aquatic plant information available, covering approximately 20% of lakes in the database.

32. Figure 2 shows the average proportion of lakes of each lake type containing exotic plant and fish species. Based on the FENZ data, it is evident that nationally dune lakes in particular tended to have higher proportions of lakes affected by exotic plants (17%) and fish (16%) introductions compared with other lake types, with the exception of volcanic and swamp-formed lakes which had the highest proportion of lakes affected by exotic aquatic plants (26%) and exotic fish (20%) respectively.

33. However when only the subset of all dune lakes within the Manawatu-Whanganui region were considered, the Manawatu-Whanganui lakes had the highest average proportions of both exotic aquatic plants (45% of lakes) and exotic fish (26% of lakes) in the country. These again are likely to be conservative estimates given that only a relatively small portion of the lakes have been sampled to assess incursion status for exotic plants and fish. Within lakes of the four water management subzones 66% of the lakes are known to contain exotic aquatic plant species (predominantly hornwort, oxygen weeds, and *Potamogeton crispus*) and 33% are known to contain exotic fish species.

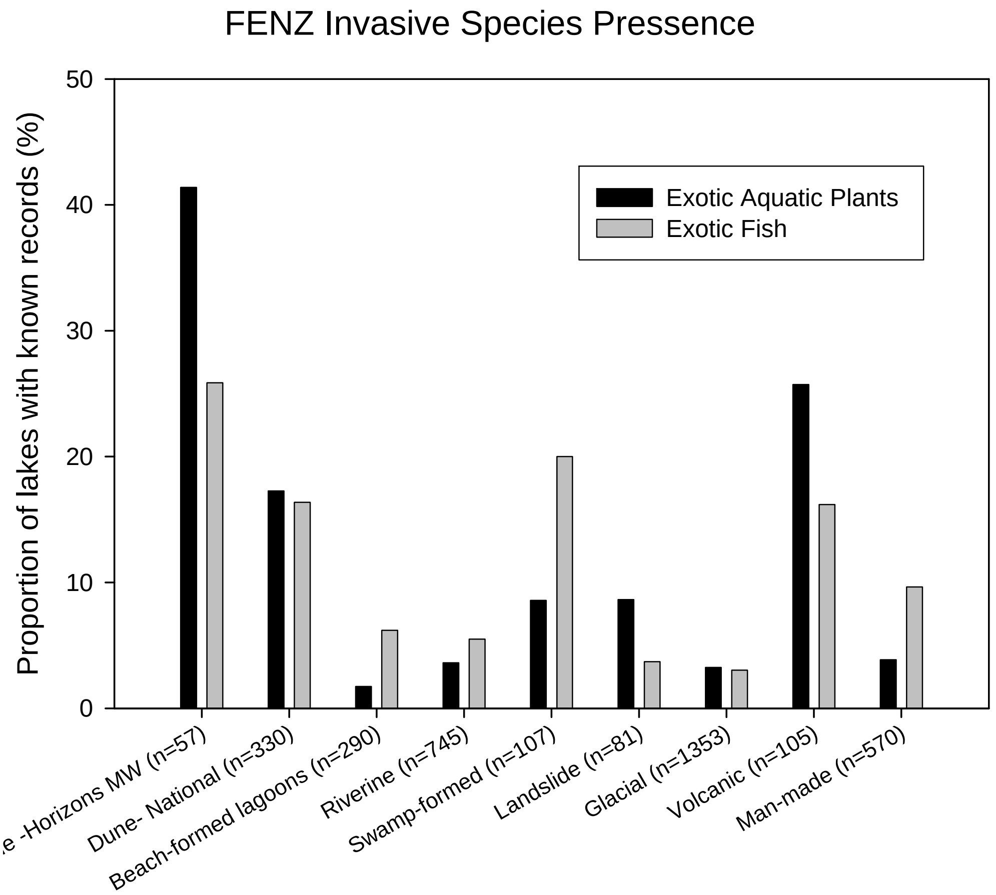

Figure 2. Average proportion of lakes of each lake type containing exotic aquatic plant and fish species. The dune lake category is broken into averages both nationally and for the Manawatu-Whanganui region

In summary

- Dune lakes are unique freshwater ecosystems on both a national and international scale, and can contain distinctive biological communities

- At a national scale dune lakes have been significantly more affected by catchment modification in comparison to other lake types in New Zealand**.** This is mainly due to the extent of vegetation clearance in the catchment and the extent of pastoral agriculture and urban development. The overall catchment condition index of dune lakes were the lowest of all natural lake classes in New Zealand.

- In the Manawatu-Whanganui region this trend of catchment modification is even more pronounced. Dune lakes contained in water management subzones Hoki_1a, Hoki_1b, West_4 and West_5 had similar levels of catchment modification to other dune lakes in the region.

- Exotic species records are high for dune lakes, particularly within the Manawatu-Whanganui region and in water management subzones Hoki_1a, Hoki_1b, West_4 and West_5.

USE OF PREDICTIVE RELATIONSHIPS BETWEEN CATCHMENT LAND-USE AND THE CONDITION OF COASTAL DUNE LAKES TO INFORM MANAGEMENT DECISIONS

34. In general, water quality data available for the limited number of lakes for which monitoring has occurred indicates high to very high levels of nutrients algal growth, with most lakes in the supertrophic to hypertrophic TLI3 range. However, the extent of water quality data presently available for dune lakes (and their inflowing tributaries) covered under the POP is limited. This is confirmed in the section 42A Reports of Ms McArthur, Mr Gilliland and Mr Gibbs.

35. In the absence of detailed quantitative information there are other less data intensive tools (which I term decision support tools) which can provide information that can be used to inform appropriate management actions. By decision support tools, I mean tools that can test predictions of management scenarios in the absence of more localised detailed site information. They include tools such as the FENZ database, and national scale models such as the CLUES nutrient model.

36. While these tools do not provide exact quantitative figures that will ultimately set management standards or outcomes of management actions, they can be used in conjunction with further monitoring to inform management actions. The tools typically rely on quantitative relationships derived from intensive investigations to calibrate models which can then be applied to other locations with less data available.

37. To this effect, I have used the data from the national CLUES model to inform a prediction of annual nutrient loading (total nitrogen (TN) and total phosphorus (TP)) to a number of dune lakes. The CLUES (Catchment Land Use and Environmental Sustainability) model was developed in a cross-agency project led by MAF and involving NIWA, AgResearch, HortResearch, LandCare Research, and Lincoln Ventures which relates land-cover information and hydrology to calculate annual total N runoff in a leaching model combined with a regionally based regression model and implemented within a spatial catchment framework (Woods et al., 2006). The output of the model is a prediction of annual total nitrogen or phosphorus loading in tonnes per year to the lake (summed for all inflowing tributaries).

38. To test and verify the likely accuracy of the predicted nutrient loadings from the CLUES model and their applicability to dune lakes within the Manawatu-Whanganui region, I correlated the CLUES model predictions against in-lake water quality conditions in 18 dune lakes for which water quality data was collected as part of a national coastal lake survey.

The national coastal lake survey

39. The national coastal lake survey focused on assessing the condition of 43 lowland coastal lakes in relation to land-use pressures, with the information derived from the study used for calibrating pressure-condition relationships for lake catchments within the FENZ geodatabase (discussed in paragraphs 21-30 above). The project was funded under the Cross Departmental Research Pool (CDRP) fund administered by the Foundation for Science, Research and Technology, and was a collaborative cross-agency project involving DOC, the Ministry for the Environment, several of the Regional Councils, NIWA, Cawthron Institute, and several universities. The investigation, including analyses of the full 43 coastal lake set, has been published in Drake et al. (2009) and Drake, Kelly and Schallenberg (2011).

40. This national coastal lake survey focused on shallow lakes exclusively (cut-off depth of less than 10m) because most coastal lakes fall into this depth range, and our current scientific understanding indicates that shallow lakes function quite differently ecologically to deeper lakes because they do not thermally stratify over long periods (i.e. seasonally) like deeper lakes (Scheffer 1998). Mr Gibbs has provided a thorough description of the functional differences between shallow and deep lakes in terms of their stratification cycles in his section 42A Report, so I will not repeat this information.

41. Lakes targeted for sampling in the survey were also selected on the basis of being situated within 10km of the coastline, at less than 100m elevation. We also attempted to obtain a dataset of lakes with representative geographical coverage around New Zealand and with catchments representative of a range of land-use classes (native vegetation, pastoral agriculture, forestry), even geographical coverage, and their catchments located within a range of land-use classes (native vegetation, pastoral agriculture, forestry).

42. Of the 43 lakes sampled nationally, 18 were dune lakes, of which four occurred within the south-western portion of the Manawatu-Whanganui and Levin districts (Lake Kaitoke is in West_4). Lakes Horowhenua and Wiritoa (in Hoki_1a and West_4) also were targeted to be sampled at the time of the national lowland lake survey, but hazardous water quality from cyanobacterial blooms in these lakes at time of the field study prevented sampling from them

(Appendix 1). The 18 dune lakes included in the national survey along with their morphometric (size, depth) and water quality attributes are presented in Table 2.

43. A key finding from the national coastal lake survey was that the condition of lakes was strongly and significantly related to the conditions of their catchments as quantified by the FENZ catchment condition indicators such as catchment vegetation cover, CLUES N loading, urban impervious surfaces, and exotic species (previously discussed in paragraphs 21-30 above) (Drake, Kelly, and Schallenberg 2011).

Table 2. Freshwater Ecosystems of New Zealand (FENZ) data attributes for 18 dune lakes sampled in CDRP national coastal lake survey

Lake Name	Region	Lake Area (HA)	Catchment Area (HA)	Max Depth (m)	Catch. Pasture (%)	CLUES N Load (T/yr)	CLUES P Load (T/yr)	Catch Imperviou (%)	FENZ Catch. Index
Lake Humuhumu	Northland	139.6	879	15	28	3.7	0.42	0.2	0.47
Lake Rotokawau	Northland	25.7	1490	11	25	3.4	0.06	0.0	0.06
Shag Lake	Northland	17.4	53	0	63	1.3	0.15	0.1	0.34
Lake Kaiiwi	Northland	26.8	486	16	19	1.5	0.02	4.9	0.30
Lake Waiparera	Northland	108.6	704	6	31	2.9	0.20	0.5	0.21
Lake Ngatu	Northland	51.7	172	6.5	45	1.1	0.13	6.1	0.13
Spectacle Lake	Auckland	43.8	369	7	81	5.2	0.20	4.9	0.10
Tomarata Lake	Auckland	14.4	95	5	48	3.2	0.08	3.2	0.18
Lake Whatihua	Waikato	3.9	106	3.2	92	4.2	0.16	1.4	0.06
Lake Pokorua	Waikato	25.9	486	1.2	64	8.5	0.41	3.8	0.07
Lake Vincent	Southland	17.2	314	5	88	3.0	0.05	3.3	0.27
Lake Wilkie	Otago	1.0	15	4	0	0.2	0.03	2.5	0.99
Lake Papaitonga	Manawatu	51.5	322	1.1	57	3.5	0.42	3.0	0.40
Lake Waitawa	Manawatu	15.8	243	6.3	86	2.9	0.33	2.8	0.09
Lake Marahau	Manawatu	9.8	772	5.3	91	8.2	0.85	2.7	0.07
Kaitoke lake	Manawatu	25.3	3265	1	86	14.5	0.96	3.5	0.16
Kaihoka Lake 1	Tasman	6.8	84	10.2	24	0.3	0.05	9.4	0.92
Kaihoka Lake 2	Tasman	5.3	86	11.5	29	0.3	0.05	0.0	0.87

Relationships between CLUES predicted catchment nutrient loading and in-lake trophic level index

44. In paragraphs 45 to 48 below I examine the relationship between catchment land-use and lake water quality originally conducted on the 43 lake set from

the national coastal lake survey, this time restricting it to the 18 dune lakes sampled (as referred to in paragraph 42), to examine how dune lakes respond to land-use and nutrient loading.

45. The trophic level index (TLI3) is a composite score of water concentrations of total nitrogen (TN), and total phosphorus (TP) and chlorophyll a (Burns et al. 2000). It is a commonly used metric for assessing lake trophic status (or the nutrient conditions) in New Zealand lakes. Individual nutrient (TLn, TLp) and chlorophyll (TLc) scores can also be used to assess trophic level, however the score is then based on that single component.

46. Scoring for the TLI3 index can range from less than 2 to greater than 7, with lakes in the range of 2 being very low in nutrients and clear (e.g., Lake Taupo) and lakes of greater than 7 being highly enriched and turbid (e.g., Lake Rotorua).

47. The relationship between the calculated annual CLUES total nitrogen and phosphorus loadings and the measured trophic level index (TLI3) for the 18 dune lakes is shown in Figure 3 below. The four Manawatu-Whanganui lakes are labelled on the figure.

48. Looking at the graphs in Figure 3(a), there are significant positive relationships between CLUES predicted N and P loading and the measured trophic status of the lake. Thus trophic status increases with increasing predicted CLUES nutrient loading as would be expected, and this relationship is linear. Although there is clearly some scatter in the relationship, the strength of the linear regression does indicate a reasonably good relationship between predicted N and P loading and in-lake conditions.

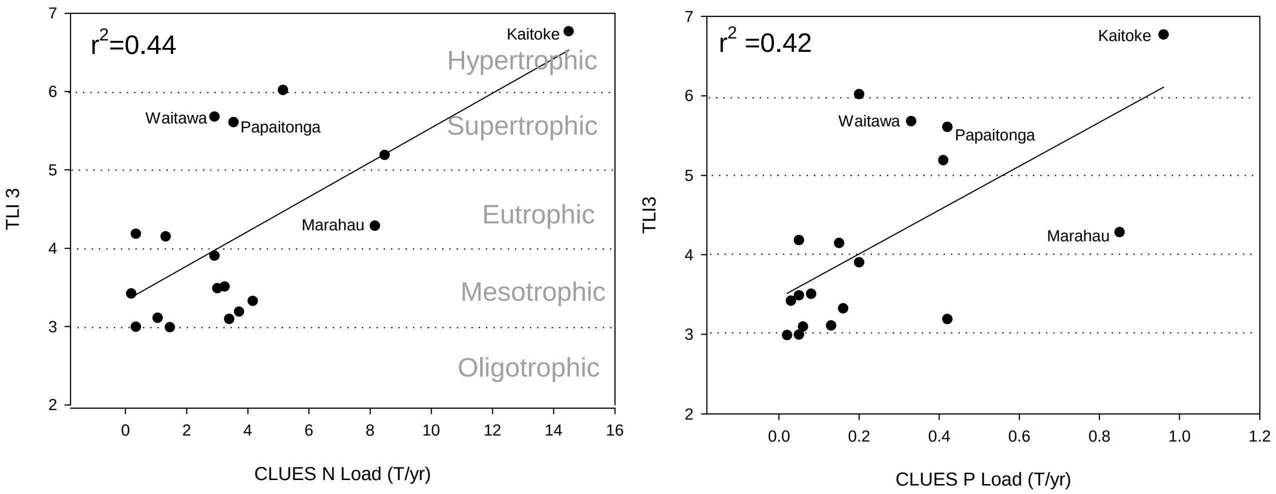

Figure 3. Relationship between CLUES predicted annual N and P loading and the measured trophic level index (TLI3) in 18 coastal dune lakes. Labelled lakes are from the Manawatu Whanganui region.

49. I acknowledge that there are a number of factors that could contribute to the less than perfect relationship between the predicted N and P loading and the trophic lake index, such as the TLI3 being based on a single sampling time, when water quality conditions in shallow lakes can vary temporally due to wind driven resuspension as well as seasonal change. However, the national coastal lakes survey timed the sampling of all lakes in late summer at the expected peak phytoplankton period to reduce this potential. Secondly, the CLUES model is run at a national scale, which uses a scaled down version of the AgResearch OVERSEER model in conjunction with the NIWA SPARROW nutrient transport model, and only calculates annual loads of total nitrogen and phosphorus. The CLUES model would also not account for other nutrient sources such as from groundwater.

50. The modelling predictions for individual lakes could be improved with greater site specific data and calculation of monthly loads, however even in the absence of such data the CLUES model can deliver useful important information on relationships between lake trophic state and catchment land-use activities. It is difficult to achieve perfect predictions from such field correlation data, and in my opinion this relationship seen in this dataset is

sufficiently robust to provide meaningful steerage for nutrient loading targets for dune lakes.

51. It is worth noting that dune lakes with relatively more pristine catchments and having lower predicted N and P loading had TLI3 scores in the mesotrophic range. These lakes were widespread around the country including Otago (Wilkie), Tasman (Kaihoka), and Northland (Kaiiwi, Humuhumu, Ngatu), thus it is unlikely that geographic factors (climate, geology) would have driven this observation.

52. The TLI3 scores of the four Manawatu-Whanganui lakes sampled ranged from supertrophic to hypertrophic. Thus there would likely need to be significant catchment nutrient loading reductions to achieve the POP water quality standards in these lakes. This is further discussed in my evidence in paragraphs 76-78.

Relationships between catchment cover and in-lake nutrients and chlorophyll

53. Data for dune lakes from the national coastal lake survey also shows that there were significant relationships between simple catchment cover information and in-lake conditions amongst the national dune lake data set (refer to Figure 4 below). For instance, the proportion of pasture cover in the catchment was positively correlated with both in-lake total N and P concentrations (although the relationship was relatively weak). More interesting is the relationship between % pasture and in-lake chlorophyll a concentration, a measure of the amount of algae growing in the lake (also used for calculating the chlorophyll portion of the TLI3 score). As I would expect the relationship is positive, but there was a group of four lakes that were located in predominantly pasture dominated catchments that had low chlorophyll biomass (circled in blue on Figure 4). Further examination of the data available for these four lakes shows that these dune lakes are heavily invaded by tall growing vascular invasive plant species such as *Ceratophyllum* and *Lagarisiphon,* which compete with planktonic algae for nutrients in their water columns. Two of these lakes with low chlorophyll biomass were from the Whanganui region (Lakes Marahau and Waitawa, see Appendix 1). When these four lakes dominated by invasive macrophytes were omitted from the regression, quite a

strong linear relationship between % pasture and chlorophyll was observed with an r^2 of 0.62. This highlights that there are complex biotic interactions in dune lakes that might act to modify the relationships between catchment nutrient loading and in-lake responses as measured by individual metrics such as chlorophyll or TLI3.

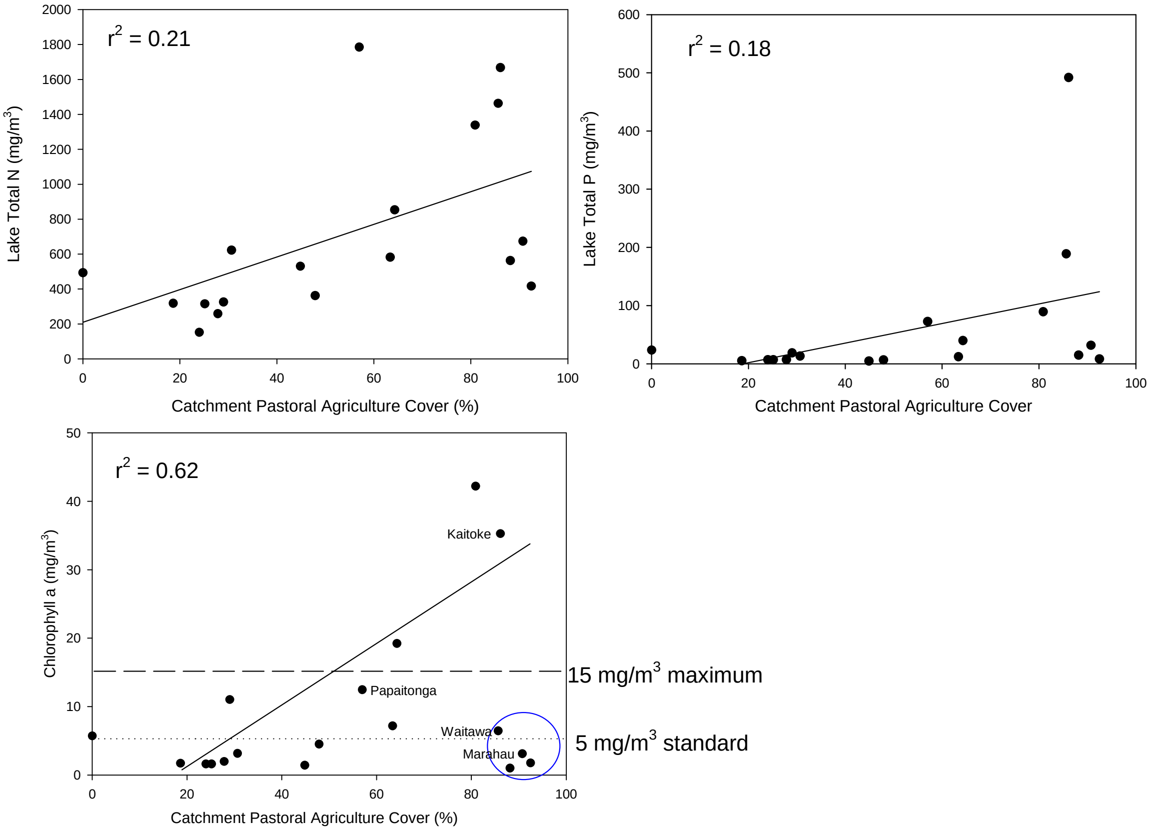

Figure 4. Relationships between catchment pastoral land cover and in-lake concentrations of total nitrogen, total phosphorus, and chlorophyll a in the 18 dune lakes.

54. In relation to water quality chlorophyll standards proposed in the POP, it is possible that the two lakes which are affected by invasive plants (Lakes Marahau and Waitawa) might meet the chlorophyll standards, but the other lakes, Kaitoke and Papaitonga, are less likely to do so. This is not just related to land-use, but also to some degree on the status of biological communities (e.g., exotic aquatic plants) present in the lake.

55. In summary, there were significant relationships between simple catchment cover information and in-lake water quality conditions, but these relationships

can be complicated by interactions with exotic plants that can affect water column nutrients and chlorophyll concentrations.

CLUES predicted nutrient loading relationships with in-lake water clarity

56. Water clarity is a significant feature for the aesthetics, recreation and ecological values of dune lakes. However, there are large and complex number of factors that contribute to water clarity in shallow lakes, making it difficult to establish robust empirical standards for this parameter. As Mr Gibbs described in his section 42A Report clarity can be affected by algal growth, wind driven resuspension of lake bottom sediments, riverine inflows, and other natural optical properties such as coloured dissolved organic materials derived from the decomposition of vegetation in the catchment (predominantly in wetland soils).

57. There are striking examples of dune lakes with exceptionally high water clarity such as Lake Taharoa in the Kaiiwi lakes of Northland which has visual clarity normally exceeding 20m (see Appendix 1). Using the water clarity data for the subset of 18 dune lakes from the national coastal dune survey I found a weak, but significant, negative relationship between the CLUES predicted N loading to the lake and water clarity depth (Figure 5a).

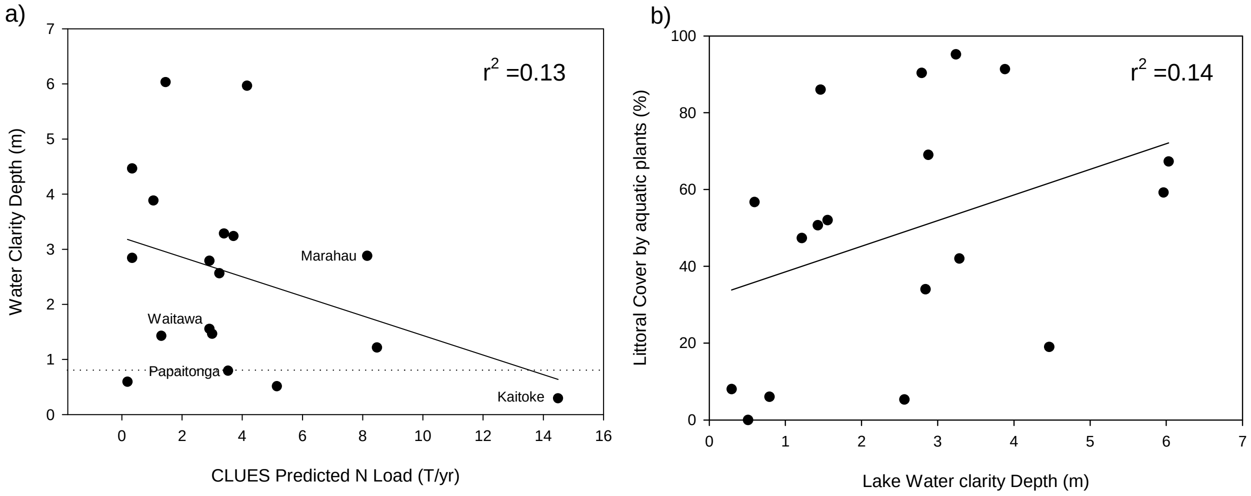

Figure 5. a) Relationship between CLUES predicted N loading and lake water clarity in 18 dune lakes showing the proposed 0.8 m water clarity standard (dotted line), and b) the relationship between lake clarity and aquatic plant cover in the littoral zone along 50 m transects outwards from the shoreline.

58. Instances of low clarity in lakes with very low predicted N loading were predominantly due to natural sources of dissolved organic materials derived from the surrounding forest and wetlands, as evidenced by high dissolved organic carbon concentrations. This was not indicative of human induced degradation in water quality.

59. As mentioned paragraph 53, some lakes can have relatively high loadings of nutrients from their catchments but the nutrients are attenuated by tall stands of exotic aquatic plants (macrophytes), which compete with phytoplankton resulting in much clearer water than would normally be expected. These exotic plant beds can also act to stabilise the lake bed and prevent resuspension of bottom sediments. Unfortunately the down-side of the exotic macrophyte story is that they outcompete (and often extirpate) native flora, and they can occur at such high biomass they cause diurnal swings of dissolved oxygen and pH as their photosynthesis shuts down at night time.

60. Our present understanding of how exotic plants undergo boom-bust cycles in shallow lakes is also an important aspect for managing weeds and nutrients in dune lakes. Schallenberg and Sorrell (2009) observed that lakes are more likely to flip between macrophyte-dominated- clear state and phytoplankton-dominated turbid state when tall growing exotic species such as *Egeria* and *Certaophyllum* were present in the lake. In nutrient rich systems these tall canopy-forming plants can intermittently become shaded by phytoplankton blooms or by growths of epiphytic filamentous algae, which promotes a dieback or a collapses in their cover, moving the lake system into a turbid state. In some cases the turbid state can return to a clear state as re-growth of aquatic plants occurs, typically over a period of years (e.g., Lake Omapere), but in others cases plants may never re-grow (e.g., Lake Ellesmere). These dynamics of lake state changes are complex, with a number of nutrient, lake-bottom, and climate (e.g., wind exposure) related factors controlling these dynamics (Scheffer 1998). This is an important aspect to consider when managing shallow lakes that contain exotic macrophytes, as is the case with most of the Manawatu Whanganui dune lakes. This is particularly true when evaluating water quality status predominantly using indexes such as nutrient

concentrations or TLI3 as in the POP because these lakes can go through longer-term cycles of clear versus turbid dominated states.

61. Focusing on lakes specifically within the Manawatu-Whanganui region, water clarity was low for Lakes Kaitoke and Papaitonga with values less than 80cm, whereas Lakes Marahau and Waitawa had intermediate clarity (1-3 m), quite possibly related to the significant exotic plant growths present in these two lakes. Horizons have not included monitoring of water clarity as part of their routine lake water quality monitoring, so further discussion of water clarity in lakes within the water management subzones is not possible at this time.

62. For completeness, Mr Gibbs suggested a 0.8 m recreational criteria for shallow lakes based on swimming recreational usage. Although this is a relatively simple standard that most lakes within the Manawatu-Whanganui (and other regions) are likely to meet, that standard would not protect ecological components of shallow lakes that are dependent on water clarity (Schallenberg and Sorrell 2009). For instance, native aquatic plants are important components of the biodiversity values of dune lakes, and provide important habitat features for macroinvertebrate and fish communities (Kelly and McDowall 2004) and in my opinion, require higher water quality than the standard proposed.

Predicting in-lake nutrient loading to meet water quality targets in Manawatu-Whanganui dune lakes

63. In the previous section (paragraphs 44 to 52) I demonstrated that land cover and outputs from predictive modelling tools is statistically related to in-lake water quality conditions in dune lakes and that information on catchment land-use, as well as predictions of nutrient loadings from models such as the CLUES, can provide useful predictive information for management purposes in relation to lake water quality.

64. In this section of my evidence I test the CLUES N loading model to predict in-lake TN concentrations for the 12 dune lakes in water management subzones Hoki_1a, Hoki_1b, West_4 and West_5, and for the 17 additional dune lakes included in the coastal lake national survey. Calculations were made for both in-lake average annual total nitrogen concentration (or TN_{Lake} in the equation

1 below) and its associated lake trophic status (TLn) for the nitrogen component of TLI3. In particular I:

a. Calculated predicted in-lake total nitrogen: In-lake average total nitrogen concentration was estimated from a nitrogen retention model using Vollenweider equations obtained from the literature (Harrison et al. 2009). The equation is shown in Equation 1:

Equation 1:

$$TN_{Lake} = 5.34\left[\frac{TN_{Inflow}}{\left(1+\sqrt{t}\right)^{0.78}}\right]$$

In this model the TN_{Inflow} is the annual average inflow concentrations of total N (mg/m^3), and t is the theoretical hydraulic retention time of the lake in years (i.e., lake volume divided by the annual inflow volume). Flow weighted average nutrient concentrations were derived from the CLUES nutrient load model which also provides mean annual flow.

b. Calculated the lake trophic index for only the nitrogen component (TLn): using equations from Burns et al. (2000) to inform the nutrient status of the lake

c. Calculated the nitrogen loading required in order to meet the standards in Schedule D of the POP (735 mg/m^3 for shallow lakes of and 337 mg/m^3 for deep lakes)

d. Calculated the nitrogen loading required in to meet a more protective standard for N in shallow lakes of 489 mg/m^3 (mid-eutrophic range)

e. Calculated the % change required from present day CLUES loading predictions to achieve the standards referred in (c) and (d) above

65. Field monitoring data of TLn were used for evaluating of the performance of the nitrogen retention model predictions where available. Further, in February

2012, I conducted a field visit to some of the lakes for which modelling predictions were made (Lakes William, Koitata, Wiritoa, Pauri, and Dudding). Although I did not measure TLI3 values at the time of the visit, I did assess visual clarity and algal bloom conditions, and most lakes looked to have visual water clarity close to their predicted TLI3 range. In some lakes there were obvious noxious algal bloom issues (e.g., Lake Wiritoa – see Appendix 1). There were also obvious exotic macrophyte stands present in some (Lakes William and Pauri) which would act to attenuate nutrient loading, but as mentioned in paragraph 60 this process can be very cyclical.

66. Set out below (Table 3) are the results. For each water management zone I have listed a number of key lakes, along with their lake area and catchment area. Note for this exercise I used the lake catchment rather than the water management subzone in order to be able to make predictions for individual lakes. As described above, the water management subzones each contain a number of lakes.

Table 3: Summary of predictions of in-Lake average annual total nitrogen concentration using the CLUES N model loading predictions. Calculation of in-lake mean annual total nitrogen concentration was made using Vollenweider models for nitrogen retention (Harrison et al. 2009), and TLn calculations was based on Protocol for Monitoring Trophic Levels of New Zealand Lakes and Reservoirs (Burns et al., 2000).

Subzone	Lake name	Lake Area (HA)	Catchment Area (HA)	Present Predicted CLUES N Loading (T/yr)	Predicted in-Lake TN (mg/m^3)	Predicted TLn	Measured TLn	Loading to meet One Plan standards (T/yr)	Loading to meet mid Eutrophic TLn (T/yr)
West_4	Wiritoa	21.8	696	4.2	837	5.2	5.2 (Supertrophic)	1.7[2] (-59%)	Not applicable
	Pauri	19.2		2.8	1215	5.7	6.9 (Hypertrophic)	1.7[1] (-40%)	1.2 (-58%)
	Kaitoke	25.3	3265	13.4	762	5.1	6.1 (Hypertrophic)	12.7[1] (-6%)	8.5 (-37%)
	Kohata	5.2	84	0.4	691	4.9	n/a	0.37[1] (meets)	0.25 (-29%)
West_5	Bernard	8.0	734	3.6	914	5.3	n/a	1.3[2] (-64%)	Not applicable
	Koitata	9.6	1406	7.9	1398	5.9	n/a	4.1[1] (-48%)	2.8 (-64%)
	Dudding	7.8	184	1.5	1254	5.7	5.6 (Supertrophic)	0.4[2] (-74%)	Not applicable
	Heaton	14.4	956	7.6	1523	6.0	n/a	3.6[1] (-53%)	2.5 (-67%)
	William	6.8	71	1.8	3431	7.0	n/a	0.4[1] (-77%)	0.3 (-83%)
	Alice	11.9	238	2.1	1435	5.9	n/a	1.0[1] (-52%)	0.8 (-62%)
	Herbert	4.7	375	1.9	1053	5.5	n/a	1.3[1] (-33%)	1.0 (-48%)
West_8[3]	Papaitonga	51.5	322	2.7	1050	5.5	6.17 (Hypertrophic)	1.8[1] (-32%)	1.3 (-51%)
Hoki 1a, 1b	Horowhenua	304.0	6253	71.6	2333	6.5	7.1 (Hypertrophic)	22.5[1] (-69%)	15.0 (-79%)

[1] Shallow lakes – meeting an average annual total N standard of 735 mg/m^3

[2] Deep lakes – meeting an average annual total N standard of 337 mg/m^3

[3] West 8 is not subject to appeal but is included in this Table because Lake Papaitonga has monitoring data available.

67. The predicted in-lake TLn values were significantly related to measured values for the lakes where field data was available to verify predictions, with the model being highly significant ($P<0.001$, R^2 0.686) and having a standard error in the prediction of TLn of 0.134 TLn units. This means that on average the nutrient model predicted TLn within 0.134 units of the actual measured field value for our 22 lake dataset, which is an accurate prediction for management purposes.

68. The two columns to the far right in Table 3 set out the loading in both tonnes per year of nitrogen, and the percentage change required in present day loading to meet the nitrogen concentration benchmarks. Thus for example, according to this model, Lake Wiritoa would require approximately a 60% reduction in nutrient load to meet the POP standard but Lake Kohata would already meet the TN POP Schedule D standards.

69. The model does indicate that for the 12 lakes considered within the appealed water management subzones, nutrient loading from inflows would be need to be reduced by on average 47% to achieve a lake trophic status of the POP standards of annual total N concentration of 735 mg/m3 for shallow lakes or 337 mg/m3 for deep lakes.

70. It would need to be reduced even further if a more protective nutrient standard was considered, such as the mid-point of the eutrophic range. I have included this comparison because in my opinion, the Schedule D standard for shallow lakes of 735 mg/m³ annual average TN, borders the eutrophic/supertrophic index, and does not adequately safeguard ecological and recreational values. Figure 3 above shows that many shallow dune lakes in modified catchments can have TLI3s in the mesotrophic to eutrophic range, thus it is my opinion that the TN and TP concentration standards should no higher than the mid-point of the eutrophic range (i.e, average total N of 489 mg/m³ and average total P of 35 mg/m³). This would reduce the potential for cyanobacterial blooms, which already occur in lakes with a TLI3 in the range 5, which is equivalent to the proposed standard. For example Lake Wiritoa, with a TLI3 of 5.2, has cyanobacterial bloom issues including toxic microcystin concentrations, as cited in Mr Gilliland’s section 42A Report. Revised

standards would be more in line with the chlorophyll algal biomass standard of 12 mg/m³ Chlorophyll a.

71. An important observation from Table 2 is that the magnitude of predicted CLUES loading is closely related to the area of the catchment. So for lakes with large catchments, even if the proportional magnitude of intensive agriculture (e.g., dairy or cropping) is low, this can still result in high overall loadings to the lake. For instance Kaitoke Lake, has a relatively low overall intensive agriculture (5% dairy and cropping combined), but has a relatively large catchment which results in high predicted N loading to the lake. This is confirmed by its present hypertrophic state as measured in recent surveys (Drake, Kelly, and Schallenberg 2011).

72. There are of course limitations to the model I have used. Greater deviation in the model predictions tended to occur in more-highly enriched lakes, with the model slightly under-predicting actual measured TLn values in hypertrophic lakes. This is sensible because TLn CLUES predictions would only account for tributary inflow contributions of N, and would ignore other potential sources such as internal cycling of nutrients from lake sediments, which is more likely to occur in lakes with nutrient-enriched lake sediments. TLn was particularly under-predicted for Lakes Horowhenua and Pauri, and these lakes are the most likely to experience significant internal loading of nutrients from short term anoxia events or wind driven resuspension of nutrient rich sediments. As Mr Gibbs also noted in his Section 42A Report, groundwater sources of nutrients can account for a significant portion (up to 50%) of nutrient loading for Lake Horowhenua specifically. There are a number of dune lakes (18% nationally) that have no connected tributary inflows, and thus CLUES predictions of nitrogen loading were not possible. This was the case for 6 of the 54 dune lakes in the Manawatu-Horizons region, two of which occur in West_5 subzone (Hickson and unnamed).

73. Aside from these limitations the model performance was statistically sound over the range of loadings considered amongst the lake set. For lakes with slightly lower trophic status (eutrophic-supertrophic), model predictions of TLn were close to field measurements, suggesting that most of the variation in lake concentration can be explained predominantly by tributary inflow sources

predicted by the CLUES model. Lakes for which no nutrient data was available to verify model predictions can be at least cross-checked against records of observations of cyanaobacterial blooms provided in Table 1 of Appendix 5 in the End of Hearing Report. For example, Lake William, which had a relatively high predicted TLn of 7.0 is reported to have cyanobacterial blooms “Often”, which supported this prediction.

74. To conclude, in-lake TN concentrations for the 13 dune lakes in Table 3 are nearly all predicted to presently exceed the POP standards for TN concentrations. This suggests that management within the lake catchments necessitates reductions in nutrient loadings to achieve the POP standards, and future landuse development needs to be managed to limit nutrient losses. All 5 lakes within these water management subzones for which water quality data was available support this finding. Discussion of the management options for improving water quality for dune lakes in the Manawatu-Whanganui region are discussed in the next section of my evidence.

In summary

- Analysis of data from the national coastal lakes survey for 18 dune lakes, four of which occur in the Manawatu-Whanganui region, demonstrates reasonably clear relationships between variables such as predicted nutrient loading (CLUES N & P), pastoral land cover, and various in-lake ecological indicators for which the POP is considering establishing water quality standards.

- Tools such as FENZ and the CLUES can be used to assess the current state of water quality for lakes with limited monitoring data.

- Based on the available monitoring data for dune lakes in the Region, the water quality of the dune lakes in the Manawatu-Whanganui region is relatively degraded in comparison to the national dataset.

- Based on available data and predictions set out above almost all dune lakes in the water management subzones considered do not meet standards proposed under the POP, and would need significant intervention to do so.

- Catchment nitrogen loading would need to be reduced by on average 47% to meet the POP standards for total nitrogen, and further reduced if a more protective nutrient standard was considered, such as the mid-point of the eutrophic range.

MANAGEMENT ACTIVITIES TO MAINTAIN OR IMPROVE WATER QUALITY OF DUNE LAKES IN THE MANAWATU-WHANGANUI REGION

75. In the following section of my evidence I discuss activities that I believe are important in the management of the dune lakes, including:
    a. Catchment nutrient management
    b. Sediment and riparian management
    c. Riparian management
    d. Exotic species management
    e. In-lake intervention measures and
    f. Monitoring

Catchment Nutrient management

76. Dr Roygard's section 42A Report (paragraph 301) states that the selection of target catchment areas for the development of Table 13-1 has been informed by the state, trends and relative contributions of non-point sources to water quality. Furthermore, the Council End of Hearing Report (McArthur et al) stated that catchments included in Table 13-1 were those with water quality issues where non-point source was identified to be a major contributor or catchments that are at risk of further degradation from intensive agriculture and are more sensitive to nutrient inputs.

77. As discussed by Mr Gibbs and Ms McArthur, the monitoring data that is available for the dune lakes does show that the water bodies within the subzones presently have water quality issues. My work at a national scale can be extrapolated to the Manawatu-Whanganui region to illustrate that water quality issues arise from modified catchments. My estimations of nutrient loadings to the lake using the CLUES model, which are significantly correlated with in-lake TLI3, show that these lakes are vulnerable to catchment land use and sensitive to nutrient inputs. Moreover, these lakes are presently unlikely to meet nutrient and water quality standards included in the POP.

78. It is my opinion, again, based on the nutrient load predictions that I have made, that in order to maintain or enhance the water quality in these catchments to meet water-user values (e.g., recreation, ecological), a significant overall nutrient reduction would be required for most lake catchments I examined. If the land-use in the catchments were to further intensify, my prediction is that the water quality would become even more degraded and move further from meeting the water quality standards under the POP. Monitoring data collected from dune lakes in the region, although sparse, supports this conclusion.

79. Mr Gibbs notes in his section 42A Report that there may be a lag of many years before the nutrient legacy from today reaches the dune lake through groundwater, i.e. even if the approach proposed in the POP to control

intensive land use and imposed nutrient loss limits on all intensive operations in many lake catchments were implemented today, the water quality of a dune lake could worsen before it improves as nutrient laden water from current land-use seeps through aquifers and into lakes (paragraph 138 and summary). Mr Gibbs also noted in his section 42A Report that as a lake is the focus of its catchment, a change in landuse within that catchment from low to high N yield will accelerate the eutrophication process, while a change from a high to low N yield land use may improve the water quality. I agree with these comments.

80. Mr Gibbs (in his section 42A Report) also discusses the potential difficulty of controlling intensive land use in lake catchments in order to improve lake water quality, particularly the uncertainty in the nutrient loadings from catchment land uses in surface streams and groundwater, the fact that the surface topography may not coincide with the groundwater aquifers, and that the groundwater catchment may be larger or smaller than the surface catchment (paragraph 126). He particularly notes the potential for Lake Horowhenua to have a larger groundwater catchment than expected from the surface topography (paragraph 134).

81. Although I generally agree with Mr Gibbs on this point, the current state of water quality suggests that both tributary and groundwater sources of diffuse nutrients will need to be managed or reduced to meet water quality standards in the POP. It is likely that both will be linked with land-use practices in their immediate water management subzone. Very large lakes such as Lake Horowhenua may be more likely to be influenced by groundwater sources beyond its immediate water management subzone (Gibbs 2011), but for smaller dune lakes localised groundwater sources have been shown to be more strongly linked with the lake in the Te Hapua dune lakes near Waikanae (Allen 2010). Therefore for smaller lakes managing landuse within the immediate water management subzone may be able to manage the risks from groundwater nutrients and would be a priority for the majority of dune lakes in the region. Data I presented in paragraphs 45-52 of my evidence also suggest that nutrient loading predictions from the immediate surface water catchments are highly correlated with in-lake water quality conditions.

Sediment and riparian management

82. Associate Professor Death has discussed in his evidence the impacts of suspended sediment on aquatic values generally. In addition to the direct influence of suspended sediment he notes that phosphorus enters waterways attached to sediment via overland flow pathways. Because phosphorus is an important nutrient influencing algal production in lakes (and can often be the limiting nutrient in lakes), controlling sediment, and therefore phosphorus, entering lakes is equally as important as managing diffuse sources of nitrogenous pollutants.

83. One method for controlling the amount of sediment entering waterways is through excluding stock from waterways. Another method to control the amount of sediment entering lakes is to ensure an adequate riparian buffer is retained, preferably planted, between activities such as cultivation and tributaries or the lake itself.

84. Horizons has already been undertaking a non-regulatory programme of working with landowners at lakes and wetlands listed in their regional wetland inventory (Regional wetland inventory and prioritisation project. February 2005, Janssen, et al 2005). This ranked list of lakes and wetlands has been used by Horizons to prioritise this work and includes the majority of the lakes in water management subzones Hoki_1a, Hoki_1b, West_4 and West_5. For example, the planting programme evident around Lake Pauri (which I specifically noted on my recent visit to the region) is a tribute to the landowners and Horizons.

85. Another example is the recent fencing and planting of the upper section of the Waiwiri stream, a tributary of Lake Papaitonga which has been undertaken through Horizons supporting the landowner (R Gill, pers comm.).

86. Again, as already articulated by Associate Professor Death in his evidence, riparian restoration, of both lake edge and tributaries is an important means of buffering the waterbody from nutrient and sediment inputs as well as providing lake and stream edge habitat.

87. Gibbs (2010) discusses the importance of lake edge wetlands to intercept nutrient rich groundwater entering the lake via shallow groundwater pathways in Lake Horowhenua. There is still a deal of uncertainty for most of the regions’ dune lakes in terms of magnitude of groundwater influences, but it is highly probable that lake edge riparian vegetation could reduce shallow groundwater nitrogen sources entering these lakes. Most of the lakes are very shallow (less than 4m), and have extensive shallow littoral (lake-edge) margins, which would tend to suggest that localised shallow groundwater flow-paths would be important connections (Allen 2010), and thus restoring lake edge wetlands is a sensible management option.

Exotic species management

88. There are a number of other issues in relation to exotic species that can either contribute to or lessen the effect of nutrient enrichment in shallow lakes. Some of the coarse fish species can accentuate nutrient loading by either disturbing the lake bed sediments, called bioturbation, or by consuming aquatic plants that would act to uptake nutrients in the lake water column (Scheffer 1998). Because dune lakes can be very shallow over their entire bed, they are particularly sensitive to these effects. Schallenberg and Sorrell (2009) observed that the presence of either grass carp, rudd or tench correlated to a catastrophic change in the regime of the lake (called flipping) from a clear state dominated by rooted aquatic plants, to being turbid and dominated by algal blooms.

89. It is still uncertain which lakes in the Manawatu-Whanganui area contain some of these exotic fish, so further fisheries surveys would be important step in understanding where these effects may potentially be a concern.

90. Exotic plants can also have a number of effects, not all of which are detrimental. Tall canopy forming plant species such as oxygen weeds and horwort can act to clear the water column by removing nutrients from the water column and stabilize lake sediments. However, as discussed earlier the downside of such plans is that they usually completely outcompete native plants (Howard Williams and Kelly 2003), can become a nuisance to

recreation, can accentuate dissolved oxygen fluctuations, and cause shifts in the native invertebrate and fish communities (Kelly and Hawes 2005), and can facilitate flipping to a turbid algal-dominated state (Schallenberg and Sorrell 2009).

91. As with exotic fish, there is an incomplete picture of the distribution of exotic plants in dune lakes from the Manawatu-Whanganui region. Because there are significant linkages with managing these species in relation to nutrient management of lakes, further survey and inventory work is recommended.

In-lake intervention measures

92. For lakes that are presently highly enriched (hypertrophic) it is probable that in addition to managing external catchment nutrient loadings, there may also need to be further in-lake lake restoration measures to reduce internal recycling from nutrient-rich lake-bed sediments. The recent review by Mr Gibbs sets out options for reducing nutrients in Lake Horowhenua through sediment capping and bioremediation actions such as controlling coarse fish, aquatic weed harvesting, fisheries manipulations, and using floating wetlands (Gibbs 2011). In my opinion the report is thorough and accurate, with the lake restoration options proposed also potentially appropriate for other shallow lakes in the region, predominantly those that are already in a highly degraded condition (hypertrophic).

93. I consider that some of these in-lake intervention methods will be more appropriate for Lake Horowhenua than other Manawatu-Whanganui dune lakes given its history of point source discharges to the lake. It has very highly nutrient enriched (particularly phosphorus) lake bed sediments by comparison to other lakes. The applicability of the in-lake intervention methods for other highly enriched lakes would need to be assessed on a case by case basis with further field investigations. It would be my expectation that the trophic status of shallow lakes that are less enriched than Lake Horowhenua (e.g., supertrophic) would be more likely to respond simply to reductions in catchment nutrient loading than in-lake interventions, but such

responses could depend on the presence of exotic plant and fish species within the lake.

94. Deep lakes such as Lake Wiritoa, Dudding, and Virginia have added complexity in that they are more likely to undergo seasonal thermal stratification cycles. During these stratified periods the bottom waters (or the hypolimnion) of the lake is essentially cut off from atmospheric re-aeration at the lake surface. As a result, the decomposition of organic matter in bottom-waters can cause anoxic conditions if the amount of organic matter is high, which is predominantly determined by the lake phytoplankton biomass.

95. While anoxia is hazardous to most aquatic life, the loss of oxygen in lake sediments stimulates internal loading of nutrients from lake sediments, and results in an even greater degree of enrichment of the lake. As such, deeper lakes are far more susceptible to internal processes contributing to nutrient problems, and thus a more protective standard for nutrient concentrations is entirely appropriate in my opinion. Because of this annual cyclic phenonomenon in deep lakes, these systems would also more likely necessitate costly in-lake restoration measures (such as sediment capping) should anoxic processes start to occur. I understand these options have been already explored for some deep lakes in the region experiencing water quality problems such as Lake Virginia.

Monitoring

96. Establishing water quality standards for lakes is a sound management strategy for setting benchmarks to maintain water quality or establish rehabilitation. Detailed discussion around the application of water quality standards to dune lakes in the POP (now Schedule D) are included within the section 42A Reports of Ms McArthur and Mr Gibbs. Although I have noted earlier in my evidence my own reservations about the specifics of some of the Schedule D numbers and the level of the standards proposed, setting some standards provides something against which to monitor outcomes of management decisions.

97. The analysis in my evidence is focused on using as best I can the available environmental monitoring data to inform decisions on standards and nutrient management in the dune lake catchments the POP considers. I have shown how data collected from other regions can be utilised to inform relationships between catchment land-use intensity and water quality of shallow dune lakes. I have also shown that there are also a number of national decision support tools such as FENZ and CLUES that can be utilised to inform these decisions.

98. While I believe management decisions must be made with the data at hand (recognising we will never have perfect data) in conjunction with modelling and decision support tools, further monitoring data is required to more accurately document the ecological condition of lakes in the region, and evaluate the outcome of management actions of catchment land-use planning decisions.

99. The section 42A Reports of Ms McArthur and Mr Gilliland have outlined monitoring data presently collected by Horizons in relation to lake water quality and it appears as though there has been limited investment in lake or inflow tributary monitoring. This is not entirely a situation unique to Horizons, at a national scale the monitoring of lakes has been limited with the exception of a few key areas such as the Bay of Plenty (Rotorua Lakes) the Waikato (lowland lakes), and a few key sites (Waituna Lagoon, Lake Ellesmere).

100. A monitoring programme should be designed to select a representative suite of the region’s dune lakes, and then, at the very least, would need to include regular (quarterly) monitoring of in-lake water quality conditions as well as inflow (and outflow where appropriate) tributary nutrient monitoring and hydrological gauging. Water quality monitoring designed around assessing whether lakes meet water quality standards in the POP would be a minimum requirement in my opinion.

101. The region’s lakes would also benefit from some biological monitoring to document exotic plant and fish species that affect the different lakes, as well as identify any unique native biodiversity values. These monitoring efforts would also assist in the prioritisation of management and monitoring focus by

the council. I would recommend the implementation of LakeSPI monitoring an aquatic plant monitoring protocol, again, to a representative set of lakes, into the monitoring framework due the important linkages between aquatic plants and other ecological attributes of dune lakes. This monitoring has been incorporated into monitoring programmes for dune lakes in other regional jurisdictions such as Northland Regional Council.

102. There are no national lake monitoring programmes at present. The Ministry for the Environment is presently leading an initiative (NEMAR- National Environmental Monitoring and Reporting) to design a nationally consistent approach for monitoring and reporting on the ecological integrity of rivers and lakes (Davies-Colley et al. 2011). This work is set to produce a series of guidance documents on national indicators and water quality parameters for monitoring lakes by June 2012, and could provide useful context around designing monitoring programmes in the region.

In summary

- The development of water quality standards for lakes is a sound management strategy for setting benchmarks to maintain water quality or establish rehabilitation targets.
- I recommend management of nutrient loads in water management subzones Hoki_1a, Hoki_1b, West_4 and West_5 in order to maintain or enhance the water quality in the dune lakes contained within them. This is supported by the present degraded water quality conditions in the dune lakes, and predictions of significant overall nutrient reduction required for most lake catchments to meet the POP nutrient standards.
- Undertaking both riparian and sediment management measures within the catchment could contribute towards important pathways for improving or maintaining water quality conditions in dune lakes within the region.

- For lakes that are presently highly enriched (hypertrophic) it is probable that significant in lake restoration measures (e.g., sediment capping, weed harvesting) will also be required in addition to catchment nutrient loading reductions to achieve improvements in water quality.

- Management of these lakes would benefit from further monitoring of in-lake and tributary nutrients concentrations (and loads) to more accurately quantify loading and responses to management of land-use activities. Further biological monitoring would also be useful for considering interactions between exotic weeds and fish and the nutrient status of dune lakes in the region.

REFERENCES

Allen, C.W. 2010. Hydrological characteristics of the Te Hapua wetland complex. Unpublished MSc thesis, Victoria University, 191p.

Allibone, R.; David, B.; Hitchmough, R.; Jellyman, D.; Ling, N.; Ravenscroft, P.; Waters, J. 2010. Conservation status of New Zealand freshwater fish, 2009. New Zealand Journal of Marine and Freshwater Research , 2010:1-17.

Ball, O.J.; Pohe, S.R.; Winterbourn, M.J. 2009. The littoral macroinvertebrate fauna of 17 dune lakes on the Aupouri Peninsula, Northland. Unpublished Report for Northland Regional Council prepared by NorthTec. FRST Envirolink Grant 681, NRLC-96. 36p.

Burns, N.M.; Bryers, G.; Bowman, E. 2000: Protocol for monitoring trophic levels of New Zealand lakes and reservoirs. Ministry for the Environment, Wellington. 138 p.

Clapcott, J.E.; Young, R.G.; Goodwin, E.O.; Leathwick, J.R. 2010. Exploring the response of functional indicators of stream health to land-use gradients. Freshwater Biology, 55, 2181–2199.

Department of Conservation. December 2004. Pukepuke Conservation Area Dune Lakes and Associated Wetland.

DeWinton, M.; Kelly, D.; Leathwick, J. 2008. Production of pressure estimates for New Zealand lakes. NIWA Client Report HAM2008-127.

Drake, D.; Kelly, D.; Schallenberg, M.; Ponder-Sutton, A.; Enright, M. 2009. Shallow coastal lakes in New Zealand: assessing indicators of ecological integrity and their relationships to broad-scale human pressures. NIWA Report CHCH 2009-04. 66p.

Drake D.C.; Kelly D.; Schallenberg M. 2011. Shallow coastal lakes in New Zealand: current conditions, catchment-scale human disturbance and determination of ecological integrity. Hydrobiologia, 658, 87–101.

Gibbs, M. 2011. Lake Horowhenua review: Assessment of opportunities to address water quality issues in Lake Horowhenua. NIWA Client Report HAM 2011-046. 118p.

Harrison, J.; Maranger, R.; Alexander, R.; Giblin, A.; Jacinthe, P.A.; Mayorga, E.; Seitzinger, S.; Sobota, D.; Wollheim, W. 2009. The regional and global significance of nitrogen removal in lakes and reservoirs. Biogeochemistry 93:143-157.

Hitchmough R, Bull L, Cromarty P. 2007. New Zealand threat classification system lists, 2005. Wellington, Department of Conservation.

Howard-Williams, C.; Kelly, D.J. 2003. Local perspectives in lake restoration, rehabilitation. In Kumagai M. & W. F. Vincent (eds), Freshwater Management: Global Versus Local Perspectives. Springer-Verlag, Tokyo, Japan, 153–175.

Irwin, J. 1975. Checklist of New Zealand lakes. New Zealand Oceanographic Institute Memoir 74. 161p.

Kelly, D.J.; McDowall, R.M. 2004. Littoral invertebrate and fish communities 25:1-14 in Harding, J.S.; Mosley, M.P.; Pearson, C.P.; Sorrell, B.K. (Eds): Freshwaters of New Zealand. New Zealand Hydrological Society and New Zealand Limnological Society, Christchurch.

Kelly, D. J.; Hawes, I. 2005. Effects of invasive macrophytes on littoral-zone productivity and foodweb dynamics in a New Zealand high-country lake. Journal of the North American Benthological Society 24: 300–320.

Kelly, D.J.; Jellyman, D.J. 2007. Changes in trophic linkages to shortfin eels (*Anguilla australis*) since the collapse of submerged macrophytes in Lake Ellesmere, New Zealand. Hydrobiologia *579*: 161–173.

Janssen, Ausseil, and Beridge, 2005. Regional Wetland Inventory and Prioritisation Project. Horizons Regional Council.

Leathwick J.R.; West, D.; Gerbeaux, P.; Kelly, D.; Robertson, H.; Brown, D.; Chadderton W.L.; Ausseil A-G. 2010. Freshwater Ecosystems of New Zealand(FENZ) Geodatabase. Department of Conservation, Hamilton.(www.doc.govt.nz/conservation/land-and-freshwater/freshwater/freshwater-ecosystems-of-new-zealand/

Leathwick J.R.; Collier, K.C..; Chadderton, W.L. 2007. Identifying freshwater ecosystems with nationally important natural heritage values: development of a biogeographic framework. Science for Conservation 274. 30p.

Livingston et al. 1986. Inventory of New Zealand Lakes Part I & II. National Water and Soil Conservation Authority. ISSN 0110-4705.

Moss, B.; Stephen, D.; Alvarez, C.; Becares, E.; Van De Bund, W.; Collings, S.E.; Van Donk, E.; De Eyto, E.; Feldmann, T.; Fernández-Aláez, C.; Fernández-Aláez, M.; Franken, R.J.M.; García-Criado, F.; Gross, E.M.; Gyllström, M.; Hansson, L.-A.; Irvine, K.; Järvalt, A.; Jensen, J.-P.; Jeppesen, E.; Kairesalo, T.; Kornijów, R.; Krause, T.; Künnap, H.; Laas, A.; Lill, E.; Lorens, B.; Luup, H.; Miracle, M.R.; Nõges, P.; Nõges, T.; Nykänen, M.; Ott, I.; Peczula, W.; Peeters, E.T.H.M.; Phillips, G.; Romo, S.; Russell, V.; Salujõe, J.; Scheffer, M.; Siewertsen, K.; Smal, H.; Tesch, C.; Timm, H.; Tuvikene, L.; Tonno, I.; Virro, T.; Vicente, E.; Wilson, D. 2003: The determination of ecological status in shallow lakes—a tested system (ECOFRAME) for implementation of the European Water Framework Directive. *Aquatic Conservation 13*: 507–549.

Rowe, D.K.; Chisnall, B.L. 1997. Distribution and conservation status of the dwarf inanga *Galaxias gracilis* (Teleostei: Galaxiidae) an endemic fish of Northland dune lakes. *The Royal Society of New Zealand, 27: 223-233.*

Schallenberg M.; Kelly D.; Clapcott J.; Death R.; MacNeil C.; Young R. 2011. Approaches to assessing ecological integrity of New Zealand freshwaters. Science for Conservation, 307, 84p.

Schallenberg M.; Sorrell B. 2009: Factors related to clear water vs turbid water regime shifts in New Zealand lakes and implications for management and restoration. New Zealand Journal of Marine and Freshwater Research 43: 701 – 712.

Scheffer, M. 1998: Ecology of shallow lakes. Kluwer Academic Publishing, Dordrecht. 357 p.

Wetzel, R.G. 1983: Limnology, Second edition. Saunders College Publishing.

Woods R.; Elliot S.; Shankar U.; Bidwell V.; Harris S.; Wheeler D.; et al. 2006. The CLUES Project: Predicting the Effects of Land-Use on Water Quality – Stage II. Prepared for Ministry of Agriculture and Forestry. p. 109. NIWA, Hamilton.

APPENDIX 1 – PICTURES OF DUNE LAKES

Picture 1- Kaihoka Lake- Tasman Area, high water clarity, some pastoral development in catchment but well buffered by intact vegetated riparian zone.

Lake Kaitoke- some intact riparian vegetation, moderate-high TLI

Lake Marahau- Some intact riparian vegetation, surface canopies of exotic macrophytes visible. Intermediate TLI.

Lake Wiritoa- Whanganui region, high TLI and surface cyanobacterial bloom.

Lake Shag- Northland Kaiiwi Lakes group, highly modified to the lake edge, moderate-high TLI.

Lake Taharoa- Kaiiwi Lakes (Northland), mostly intact vegetation, low TLI and exceptional clarity