Classification and objective bands for monitored lakes

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1 Introduction

In August 2012, the Science panel convened by the Ministry for the Environment, made suggestions for a national objectives framework for lakes. All lakes in New Zealand were considered to fall into five different classes and within each class four bands describe their water quality status, ranging from excellent to unacceptable.

Classes were grouped when there were no differences in objectives. For example, there were no differences between breakpoint objectives for upland and lowland lakes that are seasonally stratifying and clear (Table 1). The Science panel found that many lakes that were considered to sit in the ‘fair’ class were approaching a tipping point with respect to losing their macrophyte communities. This supported the group’s concept of setting a bottom line that should avoid a tipping point in a lake. Lakes beyond the bottom line, in the unacceptable band, generally had no macrophytes.

In this report the lakes that are being monitored by the Regional Councils are tentatively sorted into the proposed classes and bands, to get a preliminary impression of the performance of the framework.

The Science panel acknowledged that some of the information that would be required to assess every lake class nationally is not available. This represents a challenge to regional councils to assess and define the appropriate class that each lake will fall in. It was suggested by the Science panel that prior to classifying lakes and determining which lakes are in which bands lakes must be examined, perhaps by the councils to determine whether lakes stratify seasonally or intermittenly, and whether the water clarity relationship is affected notably by sediment, CDOM or glacial flour. Therefore, while the classification system provides a useful framework to consider appropriate bands and bottom lines for each class, because of limited information on a number of lakes this report must be considered a tentative effort at sorting particular lakes into bands within classes. In this report, for the classification of the lakes, in particular with regard to their mixing regimes and the type of control of water clarity, it was necessary to rely on rough proxies.

Table 1. The variables and breakpoints for each lake class as determined by the Science panel.

Seasonally stratified, clear, upland and lowland

	TP	TN	Chl a	Secchi	DO (%)
Excellent	10	160	2	15	80
Good	20	350	5	7	60
Fair	50	750	12	3	50
Unacceptable					

Seasonally stratified, optically challenged, upland

	TP	TN	Chl a	Secchi	DO (%)
Excellent	10	160	2		60
Good	20	350	5		50
Fair	50	750	12		40
Unacceptable					

Seasonally stratified, optically challenged, lowland

	TP	TN	Chl a	Secchi	DO (%)
Excellent	10	160	2		80
Good	20	350	5		60
Fair	50	750	12		50
Unacceptable					

Polymictic, clear, upland and lowland

	TP	TN	Chl a	Secchi	DO (%)
Excellent	10	300	2	7	
Good	20	500	5	3	
Fair	50	800	12	1	
Unacceptable					

Polymictic, optically challenged, upland and lowland

	TP	TN	Chl a	Secchi	DO (%)
Excellent	10	300	2		
Good	20	500	5		
Fair	50	800	12		
Unacceptable					

Brackish

	TP	TN	Chl a	Secchi	DO (%)
Excellent	10	160	2		
Good	20	350	5		
Fair	50	750	12		
Unacceptable					

2 Methods

To determine the bands within the classes for each lake, median data were used from the national monitoring for 2005-2009 (114 lakes), reported in Verburg et al. (2010) and for the four main hydro lakes in the Waikato River data five year medians were derived from the report by Beard (2010). In the Waikato hydro lakes Ohakuri, Whakamaru, and Waipapa samples were collected at the tailrace. Narrows Bridge was used as a surrogate for Karapiro tailrace on the advice of Bill Vant. With the Waikato hydro lakes included we have TN and TP medians for 118 lakes and chlorophyll *a* medians for 112 lakes.

The Lake Science panel, discussing the classification system to use when considering the objectives for lakes, focussed on two factors, lake size and optical characteristics of water. There was detailed discussion around what lake size refers to. Considered were lake area, depth and residence time. Depth was considered to be the most important size factor because it influences a lake's mixing regime. It was decided to distinguish between two states related to lake size, and lakes were classed as either seasonally stratified or as polymictic, where seasonally stratified refers to a persistently stratified state. However, the question how to quantify this mixing state remained unanswered. Temperature profile data are not available for many lakes and because there was no time to examine the existing data, a call had to be made on which lakes are generally seasonally stratifying lakes and which are polymictic. For this report it was therefore decided to use the maximum depth to classify lakes in terms of stratification. Lakes deeper than 15 m are classified as seasonally stratified while those <15 m deep are considered polymictic. Lake Rotorua was an exception because it is known to be polymictic although the maximum depth is 45 m. The maximum depth was used because this statistic is available for all monitored lakes. Mean depth would be a better metric but is not available for most lakes.

In addition, two states were defined depending on what controls water clarity: clear and optically challenged. Optically challenged refers to lakes where under water light attenuation is strongly affected by from non-algal sources, i.e. by either sediment such as in shallow lakes where wind disturbance resuspends sediment from the bottom, humic stained lakes with significant inputs of colored dissolved organic matter (CDOM), and lakes with large inputs of glacial flour. "Clear" lakes are all other lakes and defined as having water clarity primarily controlled by algal biomass. Such lakes are deemed to be in the clear class whether the clarity is high or low. Therefore the term "clear" is confusing and is better replaced by a term clarifying that their clarity is under algal control. "Nutrient driven" versus "non-nutrient driven" water clarity would be better but for this report the terms were left as proposed during the Science panel meetings.

The cutoff between clear and optically challenged lakes is arbitrary and could be defined by deviation from the linear relationship between log beam attenuation (commonly denoted by c. The meeting notes have it as the vertical extinction coefficient K_d but this should rather be c. See Figure 1, from Davies-Colley et al. 1993 on which this idea was based) and log chlorophyll *a*. Something to that extent was suggested during the panel meeting although not put in precise words. Further work would be required to define the cutoff between the classes. The graph by Rob Davies-Colley (Fig. 1) was proposed as a starting reference. However, underwater light attenuation (either c or even K_d) has been measured in very few of the lakes and at this point it can not be used to distinguish clear from optically challenged lakes. Therefore light attenuation must be measured in all lakes that require classification. Alternatively, it is suggested to measure suspended inorganic sediment and CDOM (using measurements of absorbance as a proxy; Verburg et al. 2010; Davies-Coley and Nagels 2008) to determine which lakes are optically challenged. Although ideally an annual series of these measurements would be used, one single measurement in each lake would probably provide quite an adequate start because little seasonal variability is expected, except perhaps in wind driven sediment resuspension.

For this report, because of the lack of the necessary information, the cutoff between clear and optically challenged lakes was based on expert knowledge of the monitored lakes with inputs from Bill Vant and Marc Schallenberg and, in addition, on the relationship between Secchi depth data and chlorophyll *a* concentrations. The latter is not ideal. We have Secchi depth data of only 61% of the monitored lakes (59% when including the Waikato River hydro lakes) and, in addition, Secchi depth is not a good measure of underwater light attenuation. The presence of dissolved organic matter in the water affects K_d more than Secchi depth (MfE 1994) and the relationship between vertical light attenuation and Secchi depth is different between lakes with high sediment loads, stained lakes and other lakes. The product K_d*SD is high in humic stained lakes where reflectance in low, low in turbid lakes (which high inorganic sediment) where reflectance is high, and intermediate in clear lakes (Davies-Colley and Vant 1988; Koenings and Edmundson 1991).

To group the lakes between upland and lowland lakes a cutoff of 300m lake surface elevation was chosen.

For brackish lakes which are in a class entirely of their own the stratification regimen and the type of control of water clarity are not considered.

It was noted during the Science panel meetings that the objectives for the different bands should be valid as well for natural lakes that are used for hydro-generation, such as lakes Taupo and Manapouri. On the other hand, the bands objectives were not considered valid for developed hydro lakes, for example lakes Benmore and Karapiro, and it was suggested that these lakes should have their own objectives. These objectives were not discussed, however. For this report we used the same band objectives for man-made hydro lakes as for natural lakes.

For dissolved oxygen concentrations (DO), the breakpoint numbers (Table 1) were developed during the second Panel meeting on 8 August with DO measurements in the middle of the hypolimnia in mind. However, the group reconsidered on 14 August that circa 1 meter off the bottom is a more appropriate depth. This means that the breakpoint numbers need to be reassessed for that measurement depth. This, however, has not been done.

For this report only chlorophyll *a*, TN and TP were considered for sorting lakes into bands, as data or Secchi depth and bottom oxygen concentrations are not available for many lakes, and breakpoints for DO near the bottom were not chosen by the Science panel. In the case where qualifying variables fall within different bands it was decided by the Science panel that at least chlorophyll *a* must be met and either/or TN and TP should fall in the same band. In addition, it was suggested that high values for both TN and TP are also “not OK”. However, the Science panel spent no thought on how to summarize a lake’s overall condition when 1) none of the bands for the three variables are the same, or when TN and TP both fall in bands of higher water quality than the band for chlorophyll *a*. For this report to summarize the overall condition we used either the band that chlorophyll *a* is in or the band of TN and TP if both were worse than that of chlorophyll *a*. In the latter case, if TN and TP are in different bands then the one of higher water quality was chosen. There are however curious cases where chlorophyll *a* is deemed unacceptable while TN and TP are both in the good bands, for instance Lake Ngakeketa.

TN, TP and chlorophyll *a* data are concentrations measured in the surface water layer, above the thermocline. The sampling should use more or less the full epilimnia depth and an integrated sample should be used.

While the lake Science panel meeting on 8 August decided that all statistics used for breakpoints and bottom lines should be annual averages, in the subsequent meeting of 14 August it was decided to use annual medians instead to avoid excessive effects of outliers. Here we use the medians to sort the lakes into the bands within classes.

3 Results and Discussion

Including the four Waikato Hydro lakes, 72 lakes were classified as polymictic and 46 as seasonally stratified. There were 79 lowland lakes and 39 upland lakes. Five lakes were considered brackish.

Expert opinion classified 22 of the lakes as optically challenged. Three of these lakes are brackish and therefore their water clarity class is irrelevant because brackish lakes are in a class of their own (see table). However, a number of lakes were not well known by the members of the Science panel. In Figure 2 the relationship between Secchi depth and chlorophyll *a* is used to examine in which other lakes water clarity may be controlled by factors other than phytoplankton. The value of the beam attenuation c can be approximated as c = 6.4/Secchi depth (Kirk 1994) but because this method depends only on Secchi depth the result is no different from Figure 2. Of the 22 optically challenged lakes Secchi depth was available for 13 lakes. The relationship between Secchi depth and chlorophyll *a* in some cases appeared to contradict expert opinion (Figure 2). As a result of the relationship between Secchi depth and chlorophyll *a* the classification of Lake Rerewhakaaitu was changed from optically challenged to clear, because Secchi depth was 22% higher instead of lower than expected from the fit of Secchi depth versus chlorophyll a for the clear lakes (see figure). The 21 lakes classified as optically challenged by expert knowledge (not including Lake Rerewhakaaitu) had on average a Secchi depth 56% below that expected from the fit with chlorophyll a. Secchi depth for these 21 lakes ranged from 3 and 9% below the fit for the North and East Serpentine lakes to 93% for Lake Wairarapa. An additional 16 lakes were classified as optically challenged based on Figure 2, with the cutoff decided as a Secchi depth more than 25% lower than expected from the fit of Secchi depth and chlorophyll a in Figure 2. As a result, 37 lakes are classified as optically challenged (Fig. 3). However, there were 48 lakes for which the Secchi depth versus chlorophyll *a* relationship could not be determined because no Secchi depth data were available (including for the 4 Waikato Hydro lakes where only the black disk is used to measure water clarity). Nine of these 48 lakes were classed as optically challenged based on expert knowledge. There are likely to be more optically challenged lakes then could be identified.

The number of lakes in each objective band, by variable (TP, TN, chlorophyll *a*, and the overall score), and by class, are in Table 2. In the case where a variable has a value equal to a breakpoint between two bands the lake was assigned to the band with the better water quality. Note that for the three classes of seasonally stratified lakes the objective bands for TN, TP and chlorophyll *a* are the same. These three classes (clear, optically challenged lowland, optically challenged upland) can therefore be joined for purposes of comparison between objectives for TN, TP and chlorophyll *a*. The same is the case for the two classes of polymictic lakes (clear, optically challenged).

Of the hydrolakes, Lake Dunstan ranks as excellent for all three variables, Lake Ohakuri as fair, excellent and good for TP, TN and chlorophyll a respectively, Lake Whakamaru as fair, excellent and fair, Lake Waipapa as fair, good and good, and Lake Karapiro as fair, good and fair, respectively.

The results for each lake individually are listed in the Appendix. In all classes, 35 lakes (30%) were overall (i.e. taking into account TN, TP and chlorophyll concentrations) in the excellent band, 29 lakes (25%) in the good band, 20 lakes (17%) in the fair band, and 32 lakes (28%)

in the unacceptable band. In the three largest classes (polymictic clear, polymictic optically challenged, seasonally stratified clear) the highest percentage of lakes in the excellent band occurred in the seasonally stratified clear lakes (23 lakes, 61%). High percentages of lakes in the unacceptable band occurred in the polymictic lakes: 13 lakes (33%) of the polymictic clear lakes and 13 lakes (48%) in the polymictic optically challenged lakes.

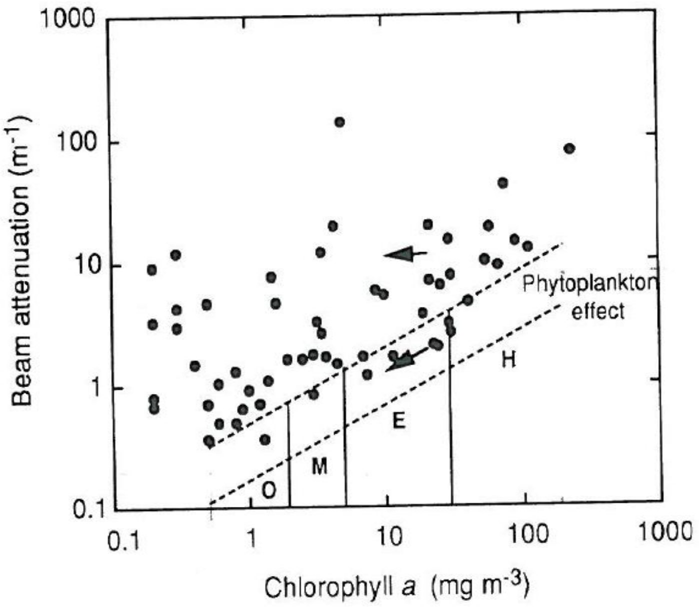

Fig. 5.11. Beam attenuation coefficient and chlorophyll *a* in New Zealand lakes (data from Howard-Williams & Vincent (1984) and Vant & Davies-Colley (1984)). The dashed lines, which are functions of [chlorophyll *a*]$^{0.62}$, encompass the band in which phytoplankton dominate attenuation (after Morel (1987)). The letters refer to the trophic classes in Table 5.5, with the vertical lines at the boundaries between the classes. The lower arrow shows how attenuation decreases in a phytoplankton-dominated lake when chlorophyll *a* falls from 20 to 10 mg m^{-3}, while the upper arrow shows the effect in a lake with appreciable non-algal attenuation.

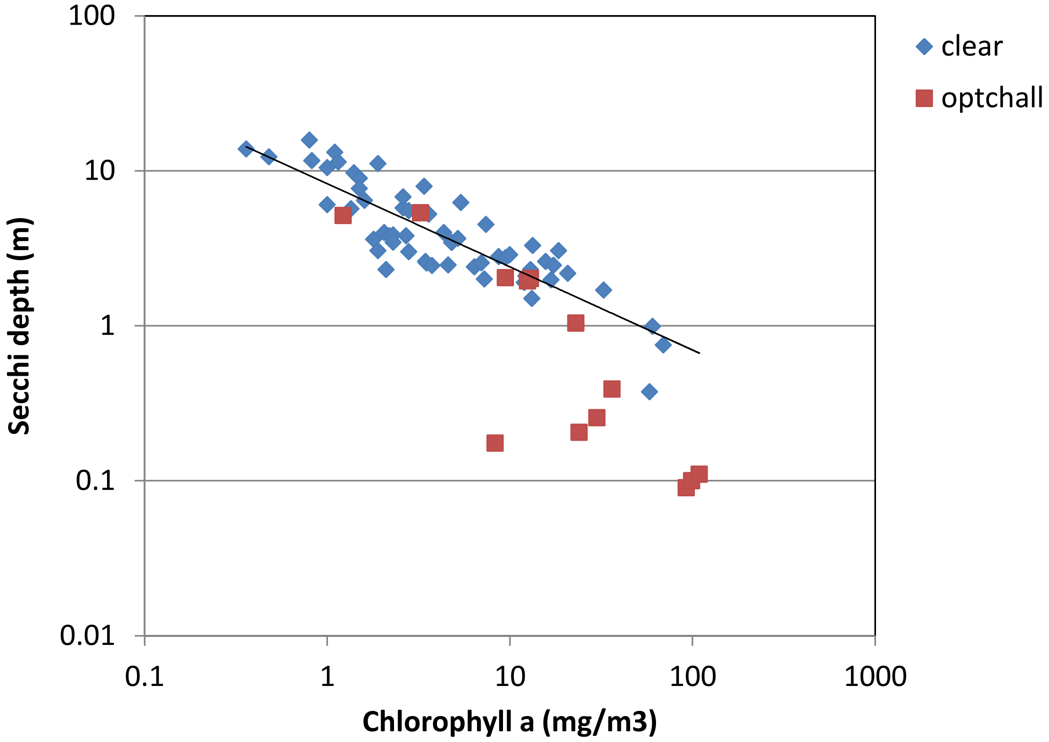

Fig. 2. Fit of Secchi depth against chlorophyll *a* (medians for 2005-2009) for 70 of the 114 monitored lakes. Optically challenged lakes ("optchall") were classified based on expert knowledge. The fit is for the clear lakes only. Based on this graph Lake Rerewhakaaitu was reclassified from optically challenged to clear while those >25% below the fit (16 lakes) were classified as optically challenged.

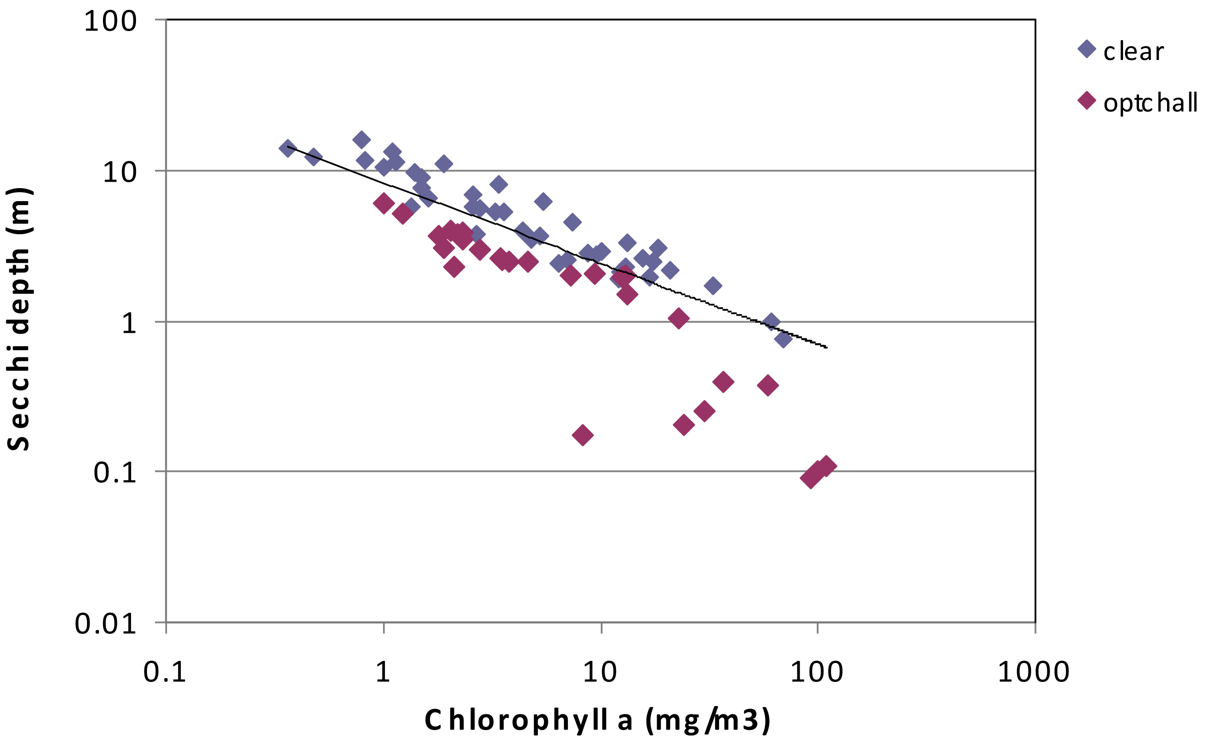

Fig. 3. As Figure 2, but with one lake (Lake Rerewhakaaitu) reclassified from optically challenged (as was suggested by expert knowledge) to clear based on the relationship between Secchi depth and chlorophyll *a* concentrations, while those >25% below the fit (16 lakes) were classified as optically challenged.

Table 2. The number of lakes in each objective band by variable (including overall score) and by class. In six of the 118 lakes no data of chlorophyll *a* concentrations were available. As a result, two of the lakes, where bands according to TN and TP did not agree, could not be placed in an overall objective band.

Seasonally stratified, clear, upland and lowland

	TP	TN	Chl a	Overall
Excellent	28	21	23	23
Good	2	9	8	8
Fair	6	6	3	3
Unacceptable	3	3	4	4

Seasonally stratified, optically challenged, upland

	TP	TN	Chl a	Overall
Excellent	3	3	3	3
Good	1	1	1	1
Fair				
Unacceptable				

Seasonally stratified, optically challenged, lowland

	TP	TN	Chl a	Overall
Excellent	1		2	1
Good	1	2		1
Fair	1	1	1	1
Unacceptable				

Polymictic, clear, upland and lowland

	TP	TN	Chl a	Overall
Excellent	6	7	6	5
Good	8	15	10	10
Fair	19	8	10	11
Unacceptable	7	10	9	13

Polymictic, optically challenged, upland and lowland

	TP	TN	Chl a	Overall
Excellent	3	3	3	2
Good	9	3	10	9
Fair	6	8	2	3
Unacceptable	9	13	12	13

Brackish

	TP	TN	Chl a	Overall
Excellent	1		1	1
Good			1	
Fair	2	2	2	2
Unacceptable	2	3	1	2

4 Extrapolation to all lakes

It is difficult to see how to extrapolate the bands for the monitored lakes to all New Zealand lakes, or to all ~3800 lakes >1ha. Sorrell (2006) and Verburg et al. (2010) used the same regression tree to extrapolate the findings for the monitored lakes to all lakes >1ha. But the seven classes in this regression tree were based on air temperature, lake area, land use and latitude, and not on the variables applied by the Science panel to distinguish classes, which are lake stratification regime, controls on optical clarity and altitude. The variables of the regression tree of Sorrell (2006) and Verburg et al. (2010) could be found in large scale data bases such as the LCDB2 and by modelling, but the classification variables selected by the Science panel, apart from altitude, cannot. Short of visiting all ~3800 lakes and measuring both maximum depth and indicators in some form of what controls water clarity, not to mention measuring temperature profiles if one wants a better handle on the mixing regime than simply using maximum depth as a proxy, the proposed classification system may be difficult to apply by extrapolation to all lakes. Extrapolation may be facilitated by examination of only those lakes that are not within National Parks (and taking into consideration whether or not the full catchment is within parks) and that are >5ha instead of >1ha.

5 Acknowledgements

The National Objectives Framework Science Panel for lakes included Bill Vant, Dave Kelly, Marc Schallenberg, Keith Hamill and Piet Verburg.

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7 Appendix

The 118 lakes monitored by Regional Councils, including four Waikato hydro lakes, sorted into the five classes of lakes that were distinguished by the Science panel and the four objective bands in each class. OC= Optically challenged.

Polymictic , clear									
Council	Lake	Altitude	Salinity	Water clarity	Stratification	TP	TN	Chl a	Overall
NRC	Lake Rotokawau	lowland	fresh	clear	polymictic	excellent	good	good	good
ECAN	Lake Hawdon	upland	fresh	clear	polymictic	excellent	good	excellent	excellent
ECAN	Lake Ida	upland	fresh	clear	polymictic	excellent	excellent	excellent	excellent
ECAN	Lake Sarah	upland	fresh	clear	polymictic	excellent	excellent	excellent	excellent
ECAN	Maori Lake (front)	upland	fresh	clear	polymictic	excellent	good	excellent	excellent
HBRC	Lake Kaweka	upland	fresh	clear	polymictic	excellent	excellent	excellent	excellent
	Ohakuri	lowland	fresh	clear	polymictic	fair	excellent	good	good
	Waipapa	lowland	fresh	clear	polymictic	fair	good	good	good
ARC	Lake Tomarata	lowland	fresh	clear	polymictic	fair	good	fair	fair
ARC	Lake Kereta	lowland	fresh	clear	polymictic	fair	unacceptable	fair	fair
	Whakamaru	lowland	fresh	clear	polymictic	fair	excellent	fair	fair
	Karapiro	lowland	fresh	clear	polymictic	fair	good	fair	fair
BOP	Lake Rotoehu	lowland	fresh	clear	polymictic	fair	good	fair	fair
NRC	Lake Rototuna	lowland	fresh	clear	polymictic	fair	fair	fair	fair
NRC	Lake Kahuparere	lowland	fresh	clear	polymictic	fair	good	fair	fair
EW	Lake Rotoroa (Hamilton	lowland	fresh	clear	polymictic	fair	unacceptable	fair	fair
NRC	Lake Waiparera	lowland	fresh	clear	polymictic	fair	unacceptable	unacceptable	unacceptable
NRC	Lake Carrot	lowland	fresh	clear	polymictic	fair	fair	unacceptable	unacceptable
NRC	Lake Karaka	lowland	fresh	clear	polymictic	fair	good	unacceptable	unacceptable
BOP	Lake Rotorua	lowland	fresh	clear	polymictic	fair	good	unacceptable	unacceptable
NRC	Lake Whakaneke	lowland	fresh	clear	polymictic	fair	fair	unacceptable	unacceptable
HRC	Lake Dudding	lowland	fresh	clear	polymictic	fair	unacceptable	unacceptable	unacceptable
HRC	Lake Virginia	lowland	fresh	clear	polymictic	fair	fair		fair
ORC	Lake Onslow	upland	fresh	clear	polymictic	fair	excellent	good	good
ECAN	Lake Emma	upland	fresh	clear	polymictic	fair	fair	fair	fair
NRC	Lake Humuhumu	lowland	fresh	clear	polymictic	good	excellent	good	good
NRC	Lake Heather	lowland	fresh	clear	polymictic	good	good	good	good
NRC	Lake Ngakapua South	lowland	fresh	clear	polymictic	good	fair	good	good
NRC	Lake Ngakapua North	lowland	fresh	clear	polymictic	good	fair	fair	fair
NRC	Lake Ngakeketa North	lowland	fresh	clear	polymictic	good	good	unacceptable	unacceptable
ECAN	Lake Georgina	upland	fresh	clear	polymictic	good	good	excellent	good
ECAN	Lake Emily	upland	fresh	clear	polymictic	good	good	good	good
ECAN	Maori Lake (back)	upland	fresh	clear	polymictic	good	good	good	good
ORC	Lake Waipori	lowland	fresh	clear	polymictic	unacceptable	unacceptable	good	unacceptable
NRC	Lake Kapoai	lowland	fresh	clear	polymictic	unacceptable	unacceptable	unacceptable	unacceptable
ECAN	Lake Rotorua	lowland	fresh	clear	polymictic	unacceptable	unacceptable	unacceptable	unacceptable
HRC	Bason Reserve Lake	lowland	fresh	clear	polymictic	unacceptable	fair		
HRC	Lake Westmere	lowland	fresh	clear	polymictic	unacceptable	unacceptable		unacceptable
HRC	Lake Pauri	lowland	fresh	clear	polymictic	unacceptable	unacceptable		unacceptable
HRC	Lake Papaitonga	lowland	fresh	clear	polymictic	unacceptable	unacceptable		unacceptable

Brackish									
Council	Lake	Altitude	Salinity	Water clarity	Stratification	TP	TN	Chl a	Overall
ECAN	Coopers Lagoon	lowland	brackish	clear	polymictic	excellent	unacceptable	excellent	excellent
ECAN	Lake Ellesmere	lowland	brackish	OC	polymictic	unacceptable	unacceptable	unacceptable	unacceptable
ECAN	Wainono Lagoon	lowland	brackish	OC	polymictic	unacceptable	unacceptable	fair	unacceptable
ES	Waituna Lagoon	lowland	brackish	OC	polymictic	fair	fair	good	fair
ORC	Lake Waihola	lowland	brackish	clear	polymictic	fair	fair	fair	fair

polymictic, optically challenged									
Council	Lake	Altitude	Salinity	Water clarity	Stratification	TP	TN	Chl a	Overall
ORC	Lake Dunstan	lowland	fresh	OC	polymictic	excellent	excellent	excellent	excellent
NRC	Lake Te Kahika	lowland	fresh	OC	polymictic	excellent	excellent	excellent	excellent
NRC	Lake Waipara	lowland	fresh	OC	polymictic	good	good	excellent	good
GWRC	Lake Wairarapa	lowland	fresh	OC	polymictic	unacceptable	fair	fair	fair
EW	Lake Rotomanuka	lowland	fresh	OC	polymictic	good	unacceptable	fair	fair
NRC	Lake Te Paki	lowland	fresh	OC	polymictic	good	excellent	good	good
HBRC	Lake Waikopiro	lowland	fresh	OC	polymictic	fair	fair	good	fair
NRC	Lake Mokeno	lowland	fresh	OC	polymictic	good	fair	good	good
NRC	Lake Ngatu	lowland	fresh	OC	polymictic	good	fair	good	good
NRC	Lake Rotokawau	lowland	fresh	OC	polymictic	good	fair	good	good
NRC	Lake Rotoroa	lowland	fresh	OC	polymictic	good	fair	good	good
NRC	Lake Waihopo	lowland	fresh	OC	polymictic	good	fair	good	good
NRC	Lake Morehurehu	lowland	fresh	OC	polymictic	excellent	good	good	good
NRC	Lake Swan	lowland	fresh	OC	polymictic	good	good	good	good
ORC	Lake Tuakitoto	lowland	fresh	OC	polymictic	unacceptable	unacceptable	good	unacceptable
NRC	Lake Wainui	lowland	fresh	OC	polymictic	fair	fair	unacceptable	unacceptable
EW	Lake Serpentine North	lowland	fresh	OC	polymictic	fair	unacceptable	unacceptable	unacceptable
EW	Lake Serpentine East	lowland	fresh	OC	polymictic	fair	unacceptable	unacceptable	unacceptable
EW	Lake Maratoto	lowland	fresh	OC	polymictic	fair	unacceptable	unacceptable	unacceptable
EW	Lake Waahi	lowland	fresh	OC	polymictic	fair	unacceptable	unacceptable	unacceptable
EW	Lake Hakanoa	lowland	fresh	OC	polymictic	unacceptable	unacceptable	unacceptable	unacceptable
NRC	Lake Omapere	lowland	fresh	OC	polymictic	unacceptable	unacceptable	unacceptable	unacceptable
ECAN	Lake Forsyth	lowland	fresh	OC	polymictic	unacceptable	unacceptable	unacceptable	unacceptable
HRC	Lake Horowhenua	lowland	fresh	OC	polymictic	unacceptable	unacceptable	unacceptable	unacceptable
ARC	Spectacle Lake	lowland	fresh	OC	polymictic	unacceptable	unacceptable	unacceptable	unacceptable
EW	Lake Whangape	lowland	fresh	OC	polymictic	unacceptable	unacceptable	unacceptable	unacceptable
EW	Lake Waikare	lowland	fresh	OC	polymictic	unacceptable	unacceptable	unacceptable	unacceptable

seasonally stratified, optically challenged, lowland									
Council	Lake	Altitude	Salinity	Water clarity	Stratification	TP	TN	Chl a	Overall
WCRC	Lake Brunner	lowland	fresh	OC	Stratified	excellent	good	excellent	excellent
TRC	Lake Rotorangi	lowland	fresh	OC	Stratified	good	fair	excellent	good
ARC	Lake Wainamu	lowland	fresh	OC	Stratified	fair	good	fair	fair
seasonally stratified, optically challenged, upland									
Council	Lake	Altitude	Salinity	Water clarity	Stratification	TP	TN	Chl a	Overall
ECAN	Lake Pukaki	upland	fresh	OC	Stratified	excellent	excellent	excellent	excellent
ECAN	Lake Tekapo	upland	fresh	OC	Stratified	excellent	excellent	excellent	excellent
ECAN	Lake Ohau	upland	fresh	OC	Stratified	excellent	excellent	excellent	excellent
HBRC	Lake Opouahi	upland	fresh	OC	Stratified	good	good	good	good

seasonally stratified, clear									
Council	Lake	Altitude	Salinity	Water clarity	Stratification	TP	TN	Chl a	Overall
ORC	Lake Wanaka	lowland	fresh	clear	Stratified	excellent	excellent	excellent	excellent
ES	Lake Te Anau	lowland	fresh	clear	Stratified	excellent	excellent	excellent	excellent
NRC	Lake Taharoa	lowland	fresh	clear	Stratified	excellent	excellent	excellent	excellent
ES	Lake Manapouri	lowland	fresh	clear	Stratified	excellent	excellent	excellent	excellent
BOP	Lake Tarawera	lowland	fresh	clear	Stratified	excellent	excellent	excellent	excellent
ORC	Lake Wakatipu	upland	fresh	clear	Stratified	excellent	excellent	excellent	excellent
ECAN	Lake Coleridge	upland	fresh	clear	Stratified	excellent	excellent	excellent	excellent
ECAN	Lake Benmore	upland	fresh	clear	Stratified	excellent	excellent	excellent	excellent
EW	Lake Taupo	upland	fresh	clear	Stratified	excellent	excellent	excellent	excellent
ORC	Lake Hawea	upland	fresh	clear	Stratified	excellent	excellent	excellent	excellent
ECAN	Lake Sumner	upland	fresh	clear	Stratified	excellent	excellent	excellent	excellent
ECAN	Lake Selfe	upland	fresh	clear	Stratified	excellent	excellent	excellent	excellent
BOP	Lake Rotoma	upland	fresh	clear	Stratified	excellent	excellent	excellent	excellent
ECAN	Lake Heron	upland	fresh	clear	Stratified	excellent	excellent	excellent	excellent
ECAN	Lake Taylor	upland	fresh	clear	Stratified	excellent	excellent	excellent	excellent
ECAN	Lake Lyndon	upland	fresh	clear	Stratified	excellent	excellent	excellent	excellent
ECAN	Loch Katrine	upland	fresh	clear	Stratified	excellent	excellent	excellent	excellent
BOP	Lake Okataina	upland	fresh	clear	Stratified	excellent	excellent	excellent	excellent
NRC	Lake Waikere	lowland	fresh	clear	Stratified	excellent	good	excellent	excellent
NRC	Lake Kai iwi	lowland	fresh	clear	Stratified	excellent	good	excellent	excellent
ECAN	Lake Camp	upland	fresh	clear	Stratified	excellent	good	excellent	excellent
BOP	Lake Tikitapu	upland	fresh	clear	Stratified	excellent	good	excellent	excellent
ECAN	Lake Alexandrina	upland	fresh	clear	Stratified	excellent	good	excellent	excellent
NRC	Lake Kanono	lowland	fresh	clear	Stratified	fair	fair	fair	fair
ARC	Lake Pupuke	lowland	fresh	clear	Stratified	fair	good	fair	fair
BOP	Lake Rotoiti	lowland	fresh	clear	Stratified	good	good	fair	fair
ECAN	Lake Grasmere	upland	fresh	clear	Stratified	excellent	excellent	good	good
ECAN	Lake Pearson	upland	fresh	clear	Stratified	excellent	excellent	good	good
ARC	Lake Ototoa	lowland	fresh	clear	Stratified	fair	excellent	good	good
ECAN	Lake Clearwater	upland	fresh	clear	Stratified	excellent	fair	good	good
BOP	Lake Rerewhakaaitu	upland	fresh	clear	Stratified	excellent	fair	good	good
HBRC	Lake Tutira	lowland	fresh	clear	Stratified	good	fair	good	good
BOP	Lake Okareka	upland	fresh	clear	Stratified	excellent	good	good	good
BOP	Lake Rotomahana	upland	fresh	clear	Stratified	fair	good	good	good
ARC	Lake Kuwakatai	lowland	fresh	clear	Stratified	fair	fair	unacceptable	unacceptable
ORC	Lake Hayes	upland	fresh	clear	Stratified	unacceptable	fair	unacceptable	unacceptable
ORC	Lake Johnson	upland	fresh	clear	Stratified	unacceptable	unacceptable	unacceptable	unacceptable
BOP	Lake Okaro	upland	fresh	clear	Stratified	unacceptable	unacceptable	unacceptable	unacceptable
HRC	Lake Wiritoa	lowland	fresh	clear	Stratified	fair	unacceptable		