TLG Advice on Lake Type FMUs

An updated summary prepared by the TLG following presentation at CSG#18
14th October 2015

Background
At CSG #14 it was decided that the lakes present in the Waikato-Waipa catchment would be managed within 4 FMUs relating to lake type (Dune, Peat, Volcanic and Riverine).

A number of questions arose from CSG#14 following this decision:
- What is the current water quality state measured against recommended attributes?
- How representative is the current WRC monitoring network?
- What management options exist?
- What current restoration activities are underway?
- Should the same attributes and bands as for the Waikato mainstem be used and should this vary by lake type?
- Limit-setting: What end state could be achievable in the different lake types?

This brief paper outlines background material and information to address those questions.

Waikato-Waipa Lakes
There are 59 named lakes in the catchment (Table 2). There are also three geothermal lakes that have been excluded as geothermal waters are outside the scope of HRWO process.

The peat lakes are the most numerous (35). They tend to be small, with 23 of the peat lakes less than 10 ha in area. All 35 peat lakes have catchments dominated by non-native vegetation. Eight are currently monitored by WRC.

There are 4 dune lakes, all less than 10 ha in size and all with nearly 100% non-native vegetation. None are currently monitored by WRC, but three have historic data available.

The 15 riverine lakes include the largest shallow lakes in the catchment (Waikare, Whangape, Waahi). Four of the lakes are currently monitored.

The five volcanic lakes in the catchment are relatively poorly known. Only two of the five have any environmental data available.

Current state
The following lake water quality attributes have previously been recommended to CSG by TLG:
- Phytoplankton biomass (Chla)
- Total N
- Total P
- Planktonic cyanobacteria
- Clarity
- E.coli

All except clarity are nationally-mandated Attributes representing Ecosystem Health (nutrients & Chlorophyll *a*) and Human Health (Cyanobacteria, E.coli).

Most Waikato-Waipa lakes breach the National Bottom line for TP, TN and Chlorophyll a (Table 1). Water quality is best at the two dune lakes with historic monitoring data, whereas riverine lakes have the worst water quality. All riverine lakes breach the national Bottom Line for TN, TP and Chla. All peat lakes breach the national bottom line for TN (i.e. 800 ppb).

Table 1: *Lake water quality state (2010-2014) by lake type for median total phosphorus (TP), total nitrogen (TN), Chlorophyll a (Chla) and cyanobacteria (80% biovol.). Colours relate to NOF bands – red is D (i.e. does not meet national bottom line), orange is C, green is B and blue is A-band. Data provided by WRC. The cell in grey (Chla at Whakatangi) is an outlier and needs checking with WRC.*

Type	**Name**	**TP**	**TN**	**Chla**	**80% biovol**
Dune	Otamatearoa	10	471	2	
Dune	Puketi	14	493	2	
	Mean	**12**	**482**	**2**	
Peat	Rotomanuka	18	1073	11	
Peat	Rotoroa	20	809	8	
Peat	Serpentine East	22	1496	9	
Peat	Maratoto	25	1777	5	
Peat	Serpentine North	30	1191	13	
Peat	Serpentine South	31	934	12	
Peat	Rotokotuku	65	1107	31	
Peat	Kainui	75	1576	28	
Peat	Areare	82	1747	25	
Peat	Horseshoe	108	1497	54	
Peat	Milicich	113	2361	138	
Peat	Ngaroto	119	2287	70	6
Peat	Mangakaware	186	1675	46	
Peat	Whakatangi	187	3240	5	
Peat	Tunawhakaheke	260	1665	19	
Peat	Mangahia	640	3102	59	
	Mean	**124**	**1721**	**33**	
Riverine	Waahi	66	1061	23	1
Riverine	TeKappa	82	1709	14	
Riverine	Hakanoa	99	1482	38	4
Riverine	Ohinewai	111	1900	45	
Riverine	Whangape	119	1860	57	20
Riverine	Okowhao	124	1822	21	
Riverine	Waikare	145	2502	94	21
Riverine	Penewaka	535	4170	35	
	Mean	**160**	**2063**	**41**	
Volcanic	Tutaeinanga	121	1522	30	
Volcanic	Ngahewa	155	843	41	
	Mean	**138**	**1183**	**36**	

Only three lakes (Serpentine East, Rotoroa and Serpentine North) achieve a C band for water clarity (Fig. 1). The remainder breach the Minimum Acceptable State for clarity (i.e. 1m).

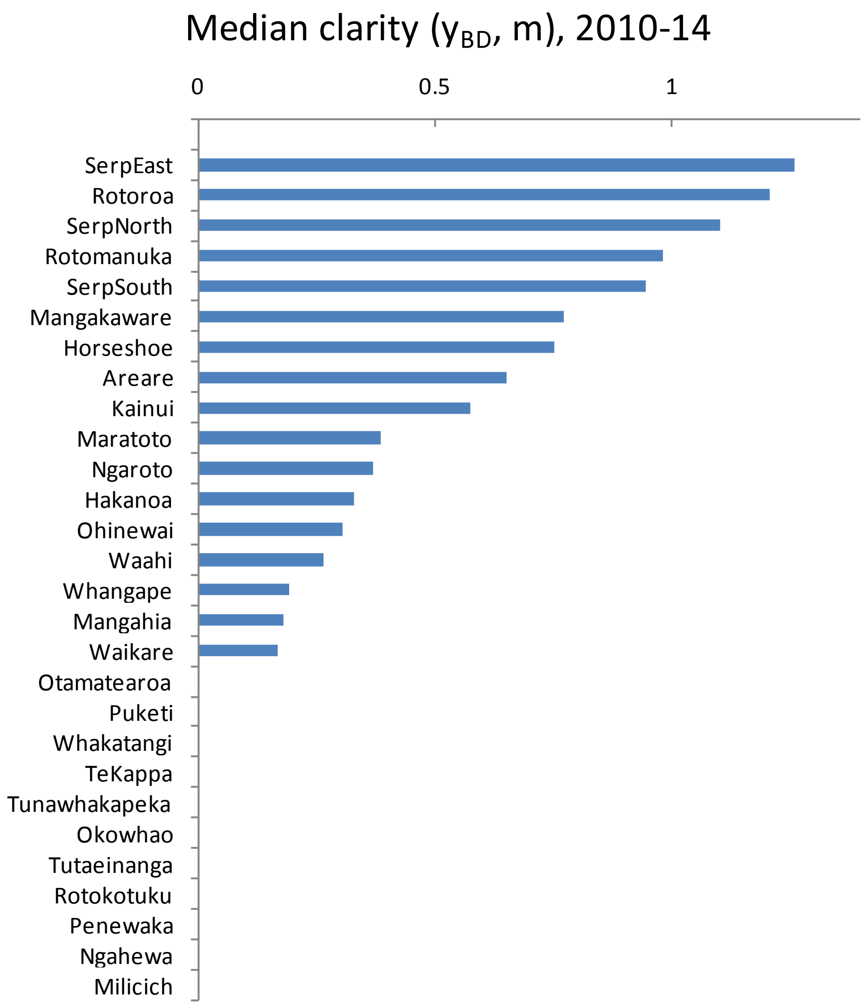

Figure 1. Median water clarity (2010-14). Figure produced by WRC.

Lake *E. coli* levels are not routinely measured in the WRC's monitoring network so we are unable to comment on the current state for this attribute.

Catchment land use has a significant effect on lake water quality, although the relationship can be modified by a range of factors including lake size and depth, intactness of riparian margins and the presence of macrophytes. Across the 59 lakes the average %native catchment vegetation is only 6.4% (maximum is 41% for Lake Kimihia).

For peat lakes with more than 5% native vegetation in their catchment (N=6) average TP was 32 ppb and Chlorophyll was 14 ppb, whereas peat lakes with less than 5% native vegetation in their catchment had an average TP of 179 ppb and Chlorophyll of 45 ppb. TN varied to a lesser extent, with 1263 ppb in the lakes with >5% native and 1996 ppb in those with less native vegetation.

Representativeness

Lakes monitored by WRC are a subset of all lakes and this will always be the case. The NPS-FM requires that monitoring against freshwater objectives need only be undertaken at representative sites within FMUs.

How might we judge representativeness?

The first step would be to ensure all lake types are covered within the current monitoring network. As shown in Table 2, Dune and Volcanic lakes have no current WRC monitoring sites, although both types have historic data. Eight of 35 peat lakes and four of fifteen riverine lakes are currently monitored. The coverage of these latter lake types (approx. ¼ of lakes within each type are monitored) seems reasonable.

Another approach would be to compare characteristics of monitored and unmonitored lakes. If both groups are reasonably similar then the monitored subset can be assumed to be representative. Monitored lakes are larger and have greater catchment areas than unmonitored lakes (Table 3). The extent of native vegetation in the catchment is relatively similar.

Table 3. Characteristics of peat and riverine lake types for monitored and unmonitored lakes.

Type	Monitoring data	Size (ha)	Catchment area (ha)	%Native
Peat	Y	25.1	413	6.6
	N	8.4	300	4.4
Riverine	Y	1367	15664	10.5
	N	47	1092	11.6

Given the emerging needs of the Healthy Rivers Plan Change (including the requirements of the NPS for Freshwater Management), a more detailed analysis should be undertaken by WRC on the representativeness of their current lake water quality monitoring network. This would include an analysis to determine whether additional sites would significantly enhance the robustness of conclusions regarding the water quality state of lakes in the region – there will always be a trade-off between the cost of such extra monitoring and its information benefit. It would seem from Table 3, that if further lakes were to be added it would be useful to include some of the smaller lakes for both riverine and peat lake types.

In looking for a cost-effective approach to addressing representativeness, WRC may need to evaluate a mixed-model approach whereby routine state and trend monitoring is supplemented by periodic extensive measurement campaigns of other lakes.

A final option for assessment of current state and trends across unmonitored lakes would be to model water quality based on established relationships between water quality and easily obtainable external drivers (e.g. land use). This approach would be subject to the uncertainties inherent in any modelling, but is likely to become more robust over time as knowledge grows from the routine monitoring and campaign data referred to above.

Management options

The complexity of lake management is highlighted in the Knowledge Network in Appendix 1. The Network shows the central role played by nutrients and sediment in achieving ecological outcomes, but there are multiple modifying factors that need to be taken into account. Each lake is likely to require an individually-tailored management plan that addresses local values, history and catchment management.

Despite the need for tailored solutions for each lake there are a range of mitigation options that should be considered for all shallow lakes. These mitigation options include active management actions within the lake and around the margins, and catchment management.

In-lake management options include wave booms, lake level management, dredging, chemical stripping of nutrients (e.g. alum dosing), netting & fish traps/gates and replanting of native macrophytes. At the lake margins, sediment traps, riparian restoration and wetland enhancement or construction will help ameliorate land use impacts. Increased flows can aid flushing of the lake, although the introduction of additional water can create other issues (e.g. changes in water level) and may be culturally unacceptable.

Catchment management that targets nutrient and sediment loads to the lake will be required in order to achieve improved ecological health long-term. All external sources of nutrients and sediment will need to be targeted. However, given the levels of exceedances of concentrations of N and P (see Table 1) and the dominance of non-native land use in all lake catchments it is unlikely that catchment-based mitigation of N, P and sediment will achieve desired lake states without major shifts in land use.

Many of the lakes within the Waikato-Waipa catchment have lost their native macrophyte beds and have “flipped” into a phytoplankton dominated state. Restoring these lakes to a more natural state may not be possible, as sediment re-suspension by wind and introduced pest fish (e.g. koi carp) create a light climate that precludes re-establishment of macrophyte beds. Introduced macrophytes also out-compete native species.

Current restoration activities

Rehabilitation of Waikato’s shallow lakes is likely to be a multi-generational issue and the Healthy Rivers Wai Ora plan change is only one of a number of rehabilitation initiatives currently underway.

The Waikato-Waipa Restoration Strategy (a partnership between Waikato River Authority, Waikato Regional Council and DairyNZ) is developing a 5-15 year restoration strategy for the Waikato-Waipa catchment. Shallow lakes in the catchment are a specific area of focus for the project, with a Technical Advisory Group formed to develop recommendations on future restoration and lake management.

Waikato Regional Council recently developed the “Waikato Regional Shallow Lakes Management Plan”. Much of the information presented by TLG to CSG has come from this plan. The Plan contains a number of important objectives that need to be considered by CSG:

Policy & planning objectives

- Appropriate objectives, targets and limits are established for the future management and enhancement of shallow lakes
- Water levels of shallow lakes and associated wetland margins are adequate to support hydrological and ecological processes and functions, and maintain or enhance the values associated with these.
- The hydrology of shallow lakes (and their associated wetland margins) is protected from the effects of further wetland drainage.

- Shallow lakes and their associated wetland margins are protected from the effects of stock access.

Information & monitoring objectives

- Sufficient information is collected by WRC to assess and rank the biodiversity (SNA) values of all shallow lakes, and this information is analysed, reported, and used as the basis of effective lake management programmes.
- Sufficient information is collected from shallow lakes to assess and report upon their condition (water quality and ecological health), and to assess the effectiveness WRC's policy and planning framework and shallow lake management programmes.
- WRC's lake level setting programme is underpinned by quality information, to ensure that shallow lake water levels are adequate to support hydrological and ecological processes and functions, and the values identified at these lakes.

Lake restoration & rehabilitation objectives

- WRC supports the development, testing and implementation of methods and techniques to maintain and/or enhance the values of shallow lakes.
- In conjunction with co-management partners, other agencies, stakeholders and landowners, WRC develops and implements integrated management and restoration programmes to protect and enhance priority shallow lakes, or valued aspects of these sites.

Lake Attributes and Bands

The NPS-FM has identified national attributes with associated bands in relation to ecosystem health and human health in lakes. For Ecosystem Health the Attributes are Phytoplankton biomass (Chl. a), Total N and Total P. For Human Health the Attributes are planktonic cyanobacteria and E.coli.

The TLG recommend that Chl. a, TN and TP be applied across all four lake FMUs and use the banding structure outlined in the National Objectives Framework. We also recommend the application of planktonic cyanobacteria and E.coli attributes and their associated bands as measures for the protection of Human Health.

Water clarity has been proposed as an Attribute specific to the Waikato. The TLG recommends its inclusion as a measure of both Ecosystem Health and as a measure relating to recreation and aesthetics across the four lake types. Water clarity does vary naturally with lake type. For example, peat lakes tend to have lower water clarity as a result of the organic material dissolved and/or suspended in the water column. Despite these differences the TLG recommends that the clarity bands established for riverine sites also be applied across the four lake types. Most monitored lakes fall into the D band (<1 m clarity) and we do not recommend changing this minimum acceptable state. For lakes with clarity >1 m we assume they will be maintained or improved as a result of Healthy Rivers and the proposed A-C bands for clarity are appropriate targets for lakes.

Nutrient levels, Chl. *a* and water clarity are widely recognised as valuable measures of lake trophic status. There are a number of other measures relating to the "naturalness" of lakes including the species composition of macrophyte communities, but the TLG suggests these fall outside the scope of Healthy Rivers.

E.coli is an Attribute for lakes in the NPS for Freshwater Management and we recommend its use in the Waikato/Waipa lakes as it is an indicator of faecal contamination and the consequent health risk associated with recreational use. There is a lack of current state data and a lack of understanding of sources and therefore effective mitigations and realistically achievable end-states.

Achievable end points for lake rehabilitation

Restoring a degraded lake to a more natural state is complex and difficult and there are few examples of successful restoration. Lakes are natural sinks for nutrients and sediments and current state often reflects historical legacies as well as current catchment land use. However, controls on catchment sources of nutrients and sediment will, over time, reduce lake trophic status and improve ecosystem health and recreation values.

The end points of restoration activities are difficult to predict and dramatic land use changes in a lake catchment may be required to achieve desired environmental outcomes. For example, Lake Waiwhakareke (Horseshoe Lake) is a small (3 ha), Waikato peat lake on the western fringe of Hamilton City. 76% of the 66 ha catchment is being retired and revegetated. Modelling by University of Waikato predicts that the lake could return to a mesotrophic state (equates to B-C bands) over a 10-15 year timeframe following restoration work. (See http://waiwhakareke.co.nz/ for further details on the restoration of Waiwhakareke).

Jenkins & Vant (2007)[1] undertook a desktop exercise to estimate the extent to which nutrient loads within shallow lake catchments could be reduced. They found around 7% of the nitrogen load and 18% of the phosphorus load could be reduced through good management practice adoption on farms in the catchment. Under more ambitious ‘potential practice’ changes (similar to the mitigations being modelled in the rivers portion of the Healthy Rivers project) the reductions in N and P increased to 36 and 39%, respectively. Changes beyond this level are likely to require changes in land use.

Limit setting for lake FMUs

The CSG has requested that the TLG provide guidance on what end-state could be achievable for the lakes and whether that differs with lake type.

Table 4 shows the percentage changes required for lakes to achieve A, B or C band status relative to monitored levels of TN, TP and Chlorophyll a. The levels of change required for most lakes, even to achieve a C band, is significant. The exception is for Dune lakes which are in a relatively good state. On average, changes in chlorophyll *a* concentrations of around 40-65% on current state are required to move the lakes to the National Bottom Line and achieve a C state (Fig. 2).

[1] Jenkins, B., Vant, B. (2007). Potential for reducing the nutrient loads from the catchments of shallow lakes in the Waikato Region. Environment Waikato Technical Report 2006/54. 23 p.

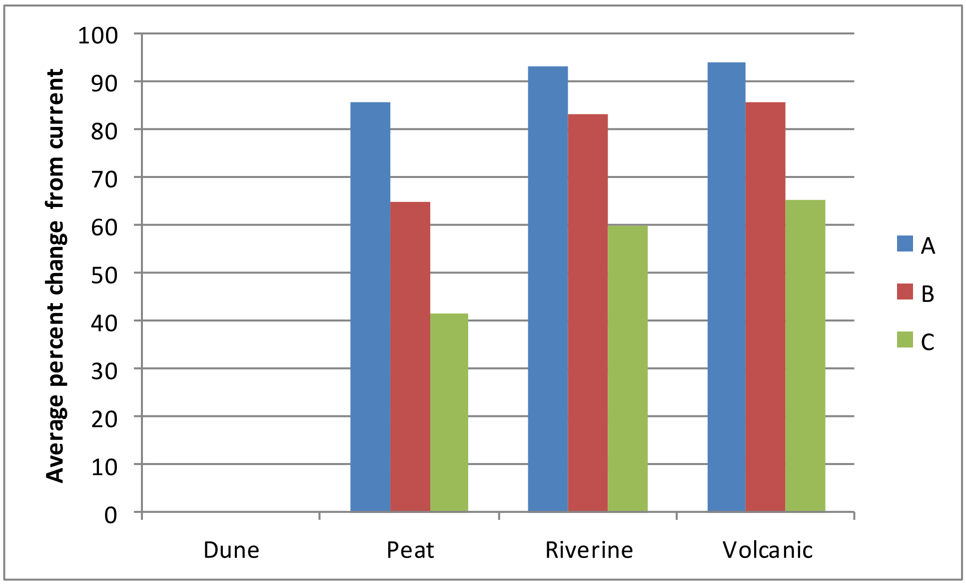

Figure 2. Levels of change in Chlorophyll a concentrations in lakes required to achieve A, B, or C attribute states.

These results highlight the significant challenge in the Waikato/Waipa lakes of meeting the National Bottom Line. With the exception of the Dune lakes, which need appropriate protection to maintain A state wherever possible, reductions in levels of N, P and chlorophyll *a* to even achieve C state for those attributes is likely to require greater actions than could be achieved through changes in land management/farm mitigations alone.

With respect to Attribute Limits the TLG suggests the CSG discuss the merits of the following desired attribute end-states:

- That there is no decline in the water quality of any lake, and
- That all lakes are at least above the National Bottom Line for chlorophyll a, TN and TP, cyanobacteria,
- That all lakes are above the minimum acceptable state for swimming (*E.coli* in B band, clarity above 1 metre)

Given the wide range of influences on Waikato/Waipa lakes, the TLG recommends that approaches to meet these Attribute Limits in the long-term be conducted within the wider lakes restoration plans being developed by the WRA-WRC-DairyNZ collaboration described above.

Table 2 – Lake summary by type

LAKE NAME	LAKE TYPE	Size (ha)	Estimated catchment size (ha)	% native veg in catchment	Historic Monitoring (Y/N)	Current WRC Monitoring	Estimated Nutrient Enrichment	ID in WRP as a significant wetland (Y/N)
Rotoiti	Dune	1.2	41.93	0	N	N	?M	N
Puketi	Dune	6.4	114.1	1	Y	N	M	N
Otamatearoa	Dune	4.9	68.3	0	Y	N	M	N
Parkinson (Kohahuake)	Dune	1.9	107.72	1	Y	N	M	N
Opuatia	Peat	6-7	?	7	N	N	?	Y
Rotokawau	Peat	22	1804	34	Y	N	H	Y
Rotokaraka	Peat	c. 6-7	?	?	N	N	?H	N
Hotoananga	Peat	19	71	0	Y	N	?	Y
Pikopiko	Peat	6.4	94	0	N	N	?H	Y
Areare	Peat	33	262	0	Y	Y	high	Y
Kainui	Peat	25	132	0	Y	N	high	N
Komakorau	Peat	2.6	619	2	N	N	?high	N
Kaituna	Peat	12	580	1	Y	N	high	Y
Whakatangi	Peat	2.7	170	0	Y	N	high	N

Tunawhakaheke	Peat	6.7	100	0	Y	N	high	Y
Rotokauri	Peat	41.7	933	0	Y	N	high	N
Waiwhakareke Horseshoe	Peat	3	66	0	Y	Y	high	N
Rotokaeo	Peat	3.1	?	0	N	N	?	N
Rotoroa	Peat	55	258	3	Y	?	moderate	N
Koromatua	Peat	9.9	200	3	Y	N	high	N
Pataka	Peat	4.6	55	13	Y	N	?high	N
Posa	Peat	2.05	95	10	Y	N	?high	N
Cameron	Peat	3.4	31	0	Y	N	?high	Y
Mangahia	Peat	8.4	354	4	Y	N	high	Y
Milicich	Peat	2.2	54	5	Y	N	high	N
Henderson's Pond	Peat	0.88	31	0	Y	N	?high	N
Maratoto	Peat	18	88	25	Y	y	high	Y
Mangakaware	Peat	12.9	238	0	Y	y	high	Y
Ruatuna	Peat	13	190	0	Y	N	high	Y
Rotomanuka	Peat	12.3	479	11	Y	Yes (from 1995)	moderate	Y
Rotomanuka South	Peat	5.4	479	11	Y	N	high	Y

Ngarotoiti	Peat	3.4	504	0	Y	N	high	Y
Ngaroto	Peat	108	1846	1	Y	y	high	Y
Rotopiko Serpentine - N Lake	Peat	5.3	163	8	Y	y	Moderate	Y
Rotopiko Serpentine - E Lake	Peat	1.6	163	8	Y	N	Moderate	Y
Rotopiko Serpentine - S Lake	Peat	8.3	163	8	Y	y	Moderate	Y
Rotopotaka	Peat	2.8	76	1	Y	N	?high	N
Rotongata	Peat	5.3	144	0	Y	N	?	N
Rotokotuku	Peat	1.1	18.5	11	Y	N	high	N
Whangape	Riverine	1450	31767	8	Y	y	high	Y
Te Kapa	Riverine	1	?	?	Y	N	high	N
Waiwhata	Riverine	8.9	?	15	N	N	high	N
Rotongaroiti	Riverine	53	2105	2	N	N	?high	y
Rotongaro	Riverine	292	1950	2	Y	N	high	Y
Kopuera	Riverine	52	250	25	Y	N	?high	Y
Penewaka	Riverine	4	?	?	Y	N	high	y
Waikare	Riverine	3442	21055	8	Y	Yes (from 1996)	high	Y

Ohinewai	Riverine	16	347	3	Y	N	high	Y
Okowhao	Riverine	21	?	5	Y	N	high	Y
Kimihia	Riverine	58	1485	41	Y	N	high	N
Waahi	Riverine	522	9221	6	Y	Y	high	N
Hakanoa	Riverine	52	613	20	Y	Y	high	N
Te Otamanui Lagoon	Riverine	5.4	?	7	Y	N	?high	N
Te Koutu	Riverine	6	416	4	Y	N	high	N
Opouri	Volcanic	23.5	636	2	?	?	?	?
Rotokawa	Volcanic	62	1090	7	?	?	?	?
Ngahewa	Volcanic	8.4	746	5	Y	N	high	N
Tutaeinanga	Volcanic	3.1	501	1	Y	N	high	N
Orotu	Volcanic	?	582	30	?	?	?	?

Table 4. Percent changes required for monitored lakes to shift to A, B or C bands from current state.

		Current			A State			B State			C State		
Type	**Lake name**	**TP**	**TN**	**Chla**	**TP**	**TN**	**Chla**	**TP**	**TN**	**Chla**	**TP**	**TN**	**Chla**
Dune	Otamatearoa	10	471	2	0	36	0	0	0	0	0	0	0
Dune	Puketi	14	493	2	29	39	0	0	0	0	0	0	0
	Mean	**12**	**482**	**2**	**14**	**38**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Peat	Rotomanuka	18	1073	11	44	72	82	0	53	55	0	25	0
Peat	Rotoroa	20	809	8	50	63	75	0	38	38	0	1	0
Peat	SerpEast	22	1496	9	55	80	78	9	67	44	0	47	0
Peat	Maratoto	25	1777	5	60	83	60	20	72	0	0	55	0
Peat	SerpNorth	30	1191	13	67	75	85	33	58	62	0	33	8
Peat	SerpSouth	31	934	12	68	68	83	35	46	58	0	14	0
Peat	Rotokotuku	65	1107	31	85	73	94	69	55	84	23	28	61
Peat	Kainui	75	1576	28	87	81	93	73	68	82	33	49	57
Peat	Areare	82	1747	25	88	83	92	76	71	80	39	54	52
Peat	Horseshoe	108	1497	54	91	80	96	81	67	91	54	47	78
Peat	Milicich	113	2361	138	91	87	99	82	79	96	56	66	91
Peat	Ngaroto	119	2287	70	92	87	97	83	78	93	58	65	83
Peat	Mangakaware	186	1675	46	95	82	96	89	70	89	73	52	74
Peat	Whakatangi	187	3240	5	95	91	60	89	85	0	73	75	0
Peat	Tunawhakaheke	260	1665	19	96	82	89	92	70	74	81	52	37
Peat	Mangahia	640	3102	59	98	90	97	97	84	92	92	74	80
	Mean	**124**	**1721**	**33**	**79**	**80**	**86**	**58**	**66**	**65**	**36**	**46**	**41**
Riverine	Waahi	66	1061	23	85	72	91	70	53	78	24	25	48
Riverine	TeKappa	82	1709	14	88	82	86	76	71	64	39	53	14
Riverine	Hakanoa	99	1482	38	90	80	95	80	66	87	49	46	68
Riverine	Ohinewai	111	1900	45	91	84	96	82	74	89	55	58	73
Riverine	Whangape	119	1860	57	92	84	96	83	73	91	58	57	79
Riverine	Okowhao	124	1822	21	92	84	90	84	73	76	60	56	43
Riverine	Waikare	145	2502	94	93	88	98	86	80	95	66	68	87

Riverine	Penewaka	535	4170	35	98	93	94	96	88	86	91	81	66
	Mean	**160**	**2063**	**41**	**91**	**83**	**93**	**82**	**72**	**83**	**55**	**55**	**60**
Volcanic	Tutaeinanga	121	1522	30	92	80	93	83	67	83	59	47	60
Volcanic	Ngahewa	155	843	41	94	64	95	87	41	88	68	5	71
	Mean	**138**	**1183**	**36**	**93**	**72**	**94**	**85**	**54**	**86**	**63**	**26**	**65**

Appendix 1: Waikato Shallow lakes knowledge network