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Assessment of the Ecological Condition of Lakes in the Waikato Region using LakeSPI - 2009

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NIWA Client Report: HAM2009-064
May 2009

NIWA Project: EVW09207

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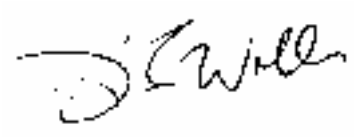

Rohan Wells Paul Champion

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Executive Summary

NIWA was contracted by Environment Waikato to assess the condition of selected lakes within the Waikato Region using LakeSPI; a method that uses Submerged Plant Indicators (SPI) to assess, monitor and report on lake condition. A total of fifty-two Waikato lakes have been assessed for this report using LakeSPI to describe:

- Pristine condition (lake plant communities in pre impacted times).
- Historical condition (lake condition as described by historical data).
- Present day condition (most recent data).

Lakes of the Waikato Region displayed a wide range of current LakeSPI scores from having no submerged vegetation (0%) to a maximum LakeSPI Index of 91%. From the lakes assessed for this report, two lakes were classified in 'excellent' condition (LakeSPI Index ≥ 75%); four lakes in 'high' condition, eleven in a 'moderate' condition, eight in a 'poor' condition and the remaining twenty seven lakes were classified as 'non-vegetated' (LakeSPI Index 0%). Lakes were also considered according to their lake type as peat, riverine, volcanic, hydro or dune lakes.

The most notable of all the lakes were Lakes Serpentine North and Serpentine East, since they were the only lakes to have retained close to their original pristine condition and are ranked in "excellent" overall condition. Despite their high LakeSPI scores, it should be noted that these lakes still show advanced signs of stress, consistent with the type of historical changes that are known to have taken place in most of the other lakes.

From the four lakes ranked in 'high' condition, two were from the volcanic group of lakes (Rotopounamu and Opouri) and two were peat lakes (Mangakaware and Rotoroa). Lake Rotopounamu was the highest ranked lake in this group because of the absence of any invasive species. A recent loss of the charophyte beds that previously dominated the submerged vegetation in Rotopounamu has resulted in a reduction of the Native Condition score which has resulted in a lower LakeSPI result than would otherwise be expected for this lake. A resurvey has been recommended to assess charophyte recovery, as a positive change in covers could see this lake being ranked as in 'excellent' condition in the future.

Eleven lakes were ranked in 'moderate' condition and although all of these lakes still supported native plant communities, all but one had significant impact by invasive weed species. Lake Harihari was the highest ranked lake in this category, with only the relatively benign weed *Elodea canadensis* recorded and significant deep-water charophyte beds beyond the main depth of impact from *E. canadensis*. Six of the seven dune lakes surveyed for this report were ranked in this 'moderate' category.

Of the eight lakes ranked as being in a 'poor' condition, all had similar LakeSPI scores that are influenced by the almost complete domination of vegetation by *Ceratophyllum demersum*, New Zealand's worst submerged weed species. This group of lakes included seven of the eight Waikato River hydro lakes and one dune lake, Otamatearoa. It is however noted that maintaining invasive species in a lake is preferable to macrophyte collapse and algal dominance.

The remaining twenty-seven lakes assessed in this report were categorised as being 'non-vegetated', either devoid of submerged vegetation or having covers that did not exceed the 10% threshold for LakeSPI assessment. All nine of the riverine lakes surveyed were categorised as 'non-vegetated' as were sixteen of the twenty-seven peat lakes assessed in this report.

LakeSPI enables the condition of different types of lakes to be compared, for example, small shallow water bodies to be compared with larger and deeper lakes. Compared nationally the Waikato Region has a higher proportion of non-vegetated lakes, indicating a high level of degradation from catchment modification and intensive agriculture. A smaller portion of Waikato lakes fall into the 'poor' category, representing extensive invasion and dominance by one of the country's worst weeds, *Ceratophyllum demsersum*. Nationally, the largest proportion of lakes fell into the 'moderate category, which in the Waikato Region contains most of the volcanic and dune that are impacted to varying degrees by invasive weeds. A relatively small proportion of Waikato lakes in the high to excellent group represent small lakes that remain close to the maximum ecological condition expected for their type.

All lakes have shown a significant reduction in LakeSPI scores from the pre 1900 'pristine' state. The most significant recent change recorded for any of the Waikato lakes was the loss of submerged vegetation in Serpentine South. In the last year, (2008/09) the submerged vegetation within the lake collapsed with only sparse remnants of native vegetation still remaining at covers that did not exceed the 10% required to generate a LakeSPI score. The most recent survey at Lake Serpentine South also gave the first record of the alien bladderwort *Utricularia gibba* for lakes of the Waikato Region, with a subsequent record at a nearby peat lake, Lake Milicich.

LakeSPI indices for these Waikato lakes will provide valuable inter-lake comparisons and enable long term monitoring of future changes in their condition. For lake managers, LakeSPI provides relevant information for regional and national reporting requirements and can be used to help assess the effectiveness of catchment and lake management initiatives. We recommend that a schedule for Lake SPI surveys, with priority and timing of future assessments, is developed that reflects current knowledge gaps, perceived lake value, stability and known threats.

1. Introduction

1.1 Study brief

NIWA was contracted by Environment Waikato to assess the condition of selected lakes in the Waikato Region using LakeSPI; a method using submerged aquatic plants as indicators of lake condition. LakeSPI assessments were carried out on each lake to estimate the following three conditions:

1. Pristine condition (lake plant communities in pre-impacted times).

2. Historical condition (described by historical data).

3. Present day condition (using most recent data).

Phase 1 of the project addressed lakes for which NIWA held data and for which significant changes were not expected, therefore no site visits were required. The first report on these lakes was completed in 2003 (Edwards and Clayton 2003). Subsequent phases of the project saw the addition of lakes that required surveys to provide an up-to-date assessment. Reports including these additional lakes were completed in 2005 (Edwards et al. 2005), 2007 (Edwards et al. 2007) and May 2008 (Edwards et al. 2008). This current report sees the addition of a further nine lakes and updated assessments on four others and brings the total of lakes within the Waikato Region that have been assessed using LakeSPI to 52.

The study brief also required all lakes to be grouped into categories based upon their current day condition. Earlier reports required lakes to be placed into one of the following categories: ‘excellent’, ‘satisfactory’ or ‘unsatisfactory’ however this report has seen a move to categories consistent throughout New Zealand. These new groupings are: ‘excellent’, ‘high’, ‘moderate’, ‘poor’ or ‘non-vegetated’. This change was made in consultation with Environment Waikato staff and will allow for more meaningful comparisons between lakes in the Waikato Region on a national level. The categories support the Ministry for the Environment initiative to ensure national consistency in terminology & reporting and are slightly modified from those suggested by Hamill & Lew 2006 based on a recent review of surveyed lakes (NIWA unpublished data).

2. Background

2.1 History of the Waikato lakes

The Waikato Region has a diverse range of more than one hundred lakes, ranging from small ponds to the largest lake in New Zealand, Lake Taupo. Lake types in the region fall under five different categories depending on where they are situated and how they were formed. These categories include: Peat lakes, Riverine lakes, Waikato River hydro lakes, west coast sand dune lakes, and lakes in the Taupo volcanic zone.

Prior to people arriving in New Zealand, the lakes would have been in their natural 'pristine' state. Periodic disruption to lake condition would have occurred with natural disturbances, such as volcanic activity, flood events or changes in the course of the Waikato River. Natural changes in lake condition also took place as the lakes aged, with key influences being changing climatic conditions, changes in catchment vegetation and progressive nutrient enrichment associated with increased productivity. Native submerged plant communities were present in all lake types as evidenced by early botanists. For example, Kirk (1871) reported a high diversity of native plant species in the shallow Waikato lakes that he inspected. Submerged vegetation often extended across the bottom of these lakes and the water was so clear that vegetation could be seen from the surface.

The small size of many of the Waikato lakes has made them especially vulnerable to change. Over the last one hundred years, lakes in the Waikato Region have undergone marked change at an unnatural rate and many have now become de-vegetated.

Three major factors have caused the accelerated decline in ecological condition of lakes in the Waikato Region: (1) declining water quality; (2) invasive fish species; and (3) invasive plant species.

Firstly there has been a decline in water clarity from the conversion of forested lake catchments to agriculture. There has been associated drainage of wetlands and removal of lake-margin vegetation, fertiliser application to pasture, and further impacts from farming activities which, collectively, have led to accelerated nutrient enrichment and siltation.

Secondly, in recent years there has been widespread liberation of invasive exotic fish species such as rudd, catfish and koi carp, which have contributed significantly to the deterioration in water quality, clarity (Rowe 2007) and the decline of submerged vegetation. Exotic fish have collectively uprooted plants, disrupted bottom sediments

and helped contribute to the present poor status of many turbid de-vegetated lakes now found throughout the region (e.g., Lake Waikare, Lake Whangape).

Thirdly, there has been extensive invasion of most lakes by submerged weed species that have largely displaced native submerged vegetation. The earliest recorded introduction was *Elodea canadensis*, which arrived in New Zealand in the late 1800s and was subsequently spread around much of the country. Successively more competitive submerged weeds established in the Waikato lakes, firstly *Lagarosiphon major*, then *Egeria densa* and *Ceratophyllum demersum*. Their combined effect has led to the virtual loss of submerged native plants from most Waikato lakes. In many of the peat and riverine lakes in the Waikato, *E. densa* formed a climax community for several years, with major impacts on ecological condition. This was often followed by subsequent vegetation collapse. In de-vegetated lakes, high biomass algae growth or re-suspension of bottom sediments commonly reduces clarity to the point where aquatic plants have not re-established.

2.2 Lake vegetation changes

In a pristine state, lakes in the Waikato Region would have once contained a diverse range of native plant species down to a depth determined by water clarity. For many of the Waikato shallow lakes it is likely that plant growth would have occurred across the entire lake bottom at some stage during their development and maturation (Figure 1). Today, there are very few Waikato lakes that remain in an all-native vegetated state, and the Serpentine (Rotopiko) Lakes are the best remaining examples.

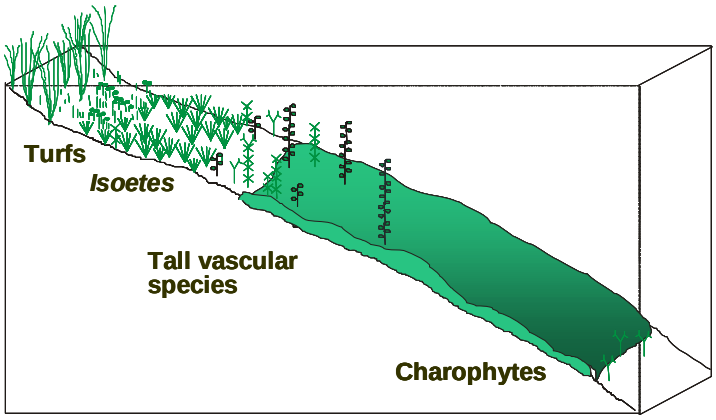


Figure 1: Depth profile illustrating the main components of native lake vegetation.

With the introduction of invasive submerged plant species during the mid 1900's, native plants in most lakes were displaced by invasive weed species, often forming tall monospecific weed beds (Figure 2). Some west coast dune lakes (Lake Taharoa, Puketi, Rotoroa and Parkinson) remain in this state and are vulnerable to collapse. Many of the Waikato lakes have now proceeded to the next and, often final stage where de-vegetation has occurred (Figure 3). Although invasive species are not favourable in terms of overall lake condition, the presence of any submerged plants in a lake is preferable to none, because they mitigate many of the symptoms of eutrophication (e.g., lock-up nutrients, maintain water clarity, compete with phytoplankton).

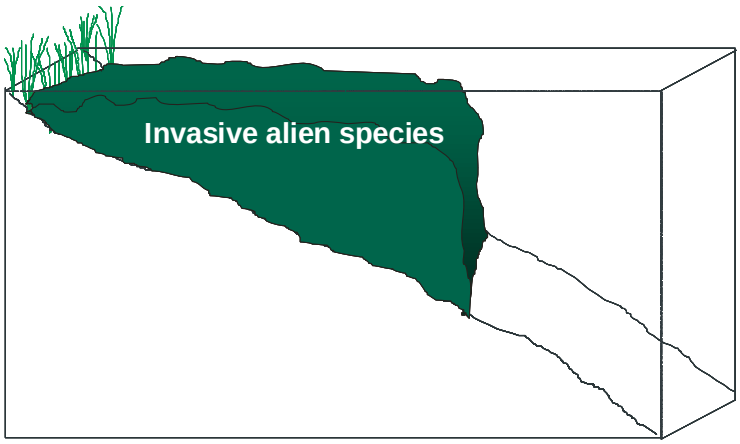


Figure 2: Depth profile illustrating the potential impact of invasive species.

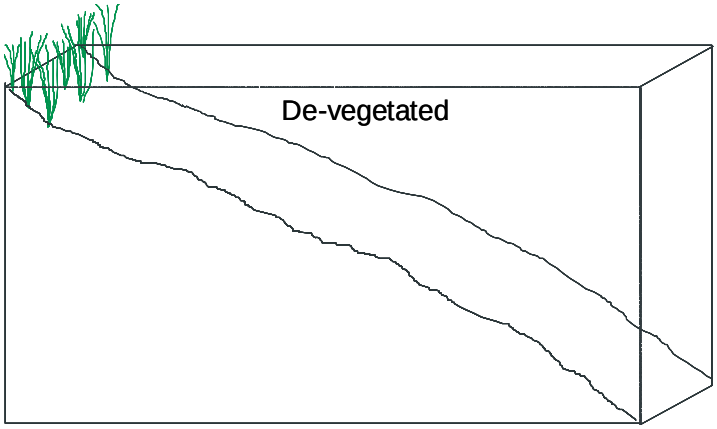


Figure 3: Depth profile illustrating a de-vegetated lake.

2.3 Plants as indicators of lake condition

Submerged plants have a number of advantages that favour their use as indicators of lake condition. For example, they are predominantly rooted or anchored to the bed of lakes. They are also macroscopic and perennial in nature, and together these features make them easy to observe, sample and identify. This contrasts with many other biota that can be highly mobile (e.g., fish) or difficult to sample, measure or identify (e.g., plankton).

Submerged plants also effectively integrate the range of environmental conditions supporting plant growth over an extended period of time prior to survey. This contrasts with other physio-chemical methods (e.g., water chemistry and Secchi disc), which may change markedly over short time periods and require frequent measurements throughout the year.

In lakes where the littoral zone (lake margin to maximum plant depth) represents a large proportion of the lake area (e.g., small shallow dune or peat lakes), the open water (or centre lake) condition can have quite different water quality and ecological condition compared to the littoral zone. Given the importance of the littoral zone to the overall ecological state and recreational value of many lakes it is important to monitor the ecological well-being and biological functioning of the littoral zone where submerged plants tend to dominate.

Increased sediment and nutrients from catchment activities, and displacement of native vegetation by invasive alien plant species are major influences on lake ecology and condition. The submerged plant indicators used in LakeSPI provide an effective means of assessing these impacts.

3. Study methods

3.1 LakeSPI

LakeSPI is a management tool that uses Submerged Plant Indicators (SPI) for assessing the ecological condition of New Zealand lakes and for monitoring trends in lake ecological condition. Key features of aquatic plant structure and composition are used to generate three LakeSPI indices:

- 'Native Condition Index' – This captures the native character of vegetation in a lake based on diversity and quality of indigenous plant communities. A higher score means healthier, deeper, diverse beds.

- 'Invasive Impact Index' – This captures the invasive character of vegetation in a lake based on the degree of impact by invasive weed species. A higher score means more impact from exotic species.

- 'LakeSPI Index' – This is a synthesis of components from both the native condition and invasive impact components of a lake and provides an overall indication of lake condition. The higher the score the better the condition.

Key assumptions of the LakeSPI method are that native plant species and high plant diversity are taken to represent healthier lakes or better lake condition, while invasive plants are ranked for undesirability based on their displacement potential and degree of measured ecological impact (Clayton & Edwards 2006). However, maintaining exotics in good condition is preferable to collapse and algal dominance.

Because lakes have differing physical characteristics that can influence the extent and type of submerged vegetation, each of the LakeSPI indices are expressed in this report as a percentage of a lake's maximum scoring potential. Scoring potential reflects the maximum depth of the lake to normalise the results from very different types of lakes. A lake scoring full points for all LakeSPI indicator criteria would result in a LakeSPI Index of 100%, a Native Condition Index of 100% and an Invasive Impact Index of 0%.

A complete description of measured characteristics is given in the technical report and user manual at www.niwascience.co.nz/ncwr/tools/lakespi. The LakeSPI method is supported by a web-reporting service found at www.lakespi.niwa.co.nz, where scores for lakes assessed to date can be searched and displayed. This secure and freely-

accessible data repository allows agencies to compare lake scores with other lakes regionally and nationally as required.

3.2 Baselines

To help put the LakeSPI indices into context, each lake has been assessed for three baselines: Pristine, Historical and Present day.

1. Pristine condition

This baseline describes the best possible condition for a lake, as it theoretically would have been in pre-impacted times. Because suitable pre-impact submerged vegetation records are not available for most lakes, for the purpose of establishing a pristine baseline we have adopted the limitation posed by lake depth as the maximum scoring potential for all lakes. This condition assumes that any lake in a pristine, undisturbed state would have supported a diverse range of submerged plant communities and have had no alien plant species. In most shallow Waikato lakes, including moderately peat stained ones, under pristine conditions, vegetation would be expected to grow across the lake bottom. This assumption may have led to an over-estimated 'historical condition' (see 2 below) of a small number of highly peat-stained lakes, because natural water staining might have constrained the depth extent of the vegetation. However, this is of limited impact on current results as most of these lakes are de-vegetated and score zero for present day lake condition.

In the case of the Waikato hydro lakes a pristine condition is not applicable as in their original state they would have existed as a river system. In these cases a best 'potential condition' is estimated in a similar way to pristine condition, but based on current lake depth.

A 'pristine condition' or 'potential condition' baseline allows lake managers to better compare present day lake condition with what the lake once would have been, or could be.

2. Historical condition

The LakeSPI method can be applied to available historic vegetation survey data using key vegetation information from macrophyte data in FBIS (Freshwater Biodata Information System - fbis.niwa.co.nz). Additional information on the nature of vegetation cover, proportion of native to invasive vegetation and the depth boundary for 10% cover was estimated from examination of the original survey sheets.

A full LakeSPI survey recommends that five baseline sites be selected from around each lake to ensure a fair representation of vegetation features and community composition. Ideally, these same baseline sites would be repeated during consecutive surveys however one limiting factor of this study is that many of the Waikato lakes have insufficient data available to ensure appropriate selection of LakeSPI sites (e.g., historical investigations at limited number of sites). Nevertheless, the information that is available, combined with an understanding of the macrophyte ecology of these lakes, has made it possible to present results that, in our view, are representative of past and present lake condition.

Reference to historical LakeSPI scores allows changes over the last few decades to be followed.

3. Present day condition

Present day conditions were calculated for each lake based on the most recent survey data. These assessments provide managers with information on present condition, a benchmark for monitoring future changes and can help to assess the effectiveness of catchment and lake management initiatives.

3.3 Information sources

Data for the LakeSPI assessments have been collected from a variety of sources. Pristine condition was assessed using information reported by early botanists such as Kirk (1871) and Cunningham et al. (1953), where characteristics of vegetation structure and species composition were used to define a natural state for these lakes. For lakes where these early descriptions were not available, expert opinion was used to extrapolate most likely pristine condition. Historical survey data was obtained from NIWA macrophyte data in FBIS, unpublished vegetation reports collated by Champion et al. (1993), and LakeSPI surveys prior to the present day survey. Present day assessments were generated from the most recent LakeSPI surveys at these lakes, or, if lacking, from surveys conducted specifically for this project. Species lists based on the most recent surveys for the lakes are presented in Appendix 1.

3.4 Study lakes

Fifty-two lakes in total have been assessed using LakeSPI. The location of lakes is indicated in Figure 4 and includes peat influenced lakes within the Waikato basin, riverine lakes adjacent to the northern reach of the Waikato River, hydroelectric lakes

along the Waikato River system, dune lakes located along the West Coast and lakes within the Taupo volcanic zone. The lakes vary in size and depth (Table 1).

Some lakes were not surveyed for this report because either they were known to be de-vegetated and recent recovery was unlikely (five lakes), or recent information was available and no major changes were expected (three lakes). The remaining 44 lakes were surveyed from late 2004 to 2009 (Table 1).

Figure 4: Location of lake groups within the Waikato Region; including dune lakes along the west coast, peat lakes in the lower Waikato basin, riverine lakes associated with the northern reach of the Waikato River, hydro lakes in the Waikato River system and lakes in the Taupo volcanic zone (source – Environment Waikato).

Table 1: Lake type, size (km^2) and depth (m) for 52 lakes assessed using LakeSPI.

Key to lake types:

Peat	Riverine	Volcanic	Hydro	Dune

Lake	Lake Type	Size (km^2)	Depth (m)	Most Recent Survey date
Aratiatia		0.5	11	02/03/2009
Arapuni		9.1	49	04/03/2009
Areare		0.34	5.1	-
Atiamuri		2.3	31	03/03/2009
Hakanoa		0.56	2.5	-
Harihari		0.18	8.6	23/03/2009
Hinemaiaia (B)		0.12	c.15	19/11/2004
Hotoananga		0.17	3	-
Kainui (D)		0.32	6.7	24/05/2005
Karapiro		7.5	34	05/03/2009
Kimihia		0.55	<1	-
Kaituna (B)		0.21	1.3	01/02/2007
Koromatua		0.068	1.2	01/02/2007
Mangakaware		0.12	4.8	25/05/2005
Mangahia		0.14	1.5	01/02/2007
Maraetai		4.12	68	16/03/2009
Maratoto		0.18	7.1	11/03/2009
Milicich		0.018	2.2	09/03/2009
Ngahewa		0.11	7.5	04/03/2008
Ngaroto		1.29	4	-
Ohakuri		14.5	40	03/03/2009
Ohinewai		0.24	4.5	03/03/2008
Okowhao		0.17	2.2	09/03/2009
Opouri		0.26	25	18/11/2004
Otamatearoa		0.063	5	09/03/2009
Parangi		0.12	17.6	20/03/2008
Parkinson		0.019	8	18/10/2004
Pataka		0.057	5	21/06/2007
Posa		0.029	4	21/06/2007
Puketi		0.059	7	18/10/2004
Rotoaira		15.32	14.6	26/03/2007
Rotoiti		0.008	7	18/10/2004
Rotokauri		0.55	4	-

Lake	Lake Type	Size (km^2)	Depth (m)	Most Recent Survey date
Rotokawau		0.32	1.2	18/06/2007
Rotomanuka		0.17	8.7	21/06/2007
Rotongaro		3.32	3.3	24/05/2005
Rotongaroiti		0.53	2*	25/05/2005
Rotopounamu		5.54	7.9	19/11/2004
Rotoroa (Hamilton)		0.54	6	08/05/2009
Ruatuna		0.17	3.2	21/06/2007
Serpentine East		0.016	4.4	10/03/2009
Serpentine North		0.053	4	10/03/2009
Serpentine South		0.083	3.6	10/03/2009
Taharoa		2.05	9.2	17/04/2007
Taupo		622.63	162.8	-
Tunawhakapeka (E)		0.08	1	18/06/2007
Tutaeinanga		0.031	11	04/03/2008
Waahi		5.37	5	28/10/2005
Waikare		34.42	2	03/03/2008
Waipapa		1.4	22	17/03/2009
Whakamaru		7.4	36	04/03/2009
Whangape		11.97	2.7	15/02/2005

*Decreased to c. 0.5 m by 2005.

4. Results

LakeSPI results for each lake have been presented in the form of a table identifying the LakeSPI Index, Native Condition Index, and Invasive Impact Index. Indices are presented as a percentage of each lakes maximum scoring potential and can be interpreted as follows:

HIGHER LakeSPI Index = Better lake condition.

HIGHER Native Condition Index = Better lake condition.

LOWER Invasive Impact Index = Better lake condition.

A lake with a LakeSPI Index of 0 has insufficient plants (plant cover <10%) to generate meaningful LakeSPI scores and is categorised as 'non-vegetated".

4.1 Peat Lakes

Having taken many thousand of years to develop, today the Waikato Region is home to the largest collection of peat lakes in New Zealand. Once part of the formerly extensive Komakorau, Rukuhia and Moanatuatua peat bogs, most of the 31 peat lakes concentrated around Hamilton City, Waikato and Waipa Districts are in a degraded state. Native submerged plants have almost entirely disappeared from the peat lakes with only five of the 21 lakes surveyed still supporting sufficient submerged vegetation (>10% cover) to generate a LakeSPI result (Table 2).

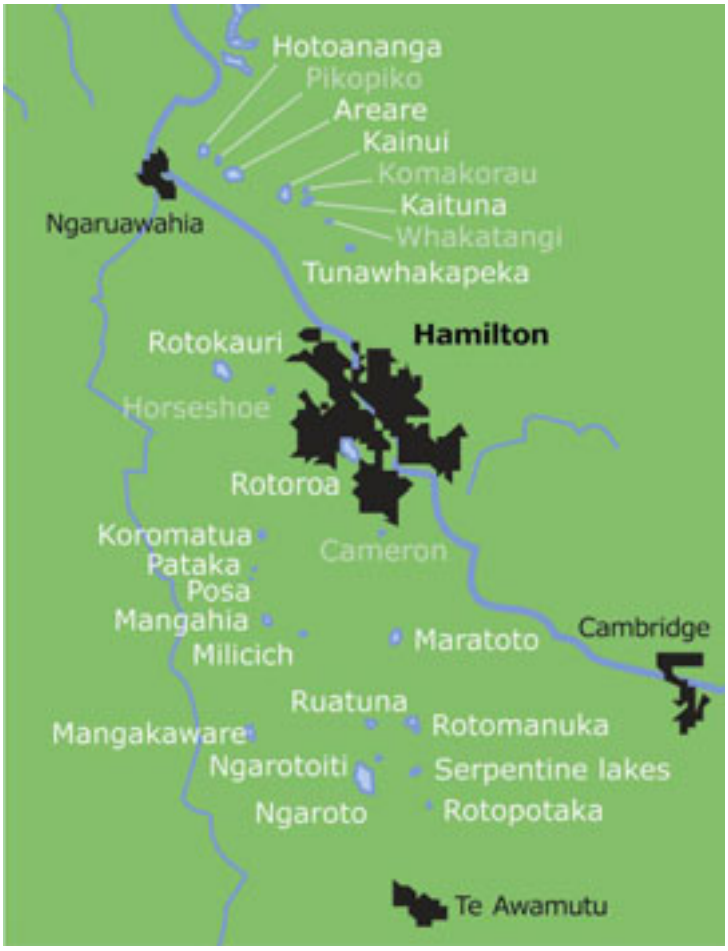


Figure 5: Location of peat lakes within the Waikato Region with assessed lakes shown in white type (source – Environment Waikato).

Table 2: Summary of LakeSPI indices for the Waikato peat lakes in order of their current lake condition.

Lake	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Serpentine East	91	78	0
Serpentine North	90	76	0
Rotoroa (Hamilton)	75	50	0
Mangakaware	63	65	33
Kainui (D)	44	28	0
Areare	0	0	0
Hotoananga	0	0	0
Kaituna	0	0	0
Koromatua	0	0	0
Mangahia	0	0	0
Maratoto	0	0	0
Milicich	0	0	0
Ngaroto	0	0	0
Pataka	0	0	0
Posa	0	0	0
Rotokauri	0	0	0
Rotokawau	0	0	0
Rotomanuka	0	0	0
Ruatuna	0	0	0
Serpentine South	0	0	0
Tunawhakapeka (E)	0	0	0

4.1.1 Lake Areare

Lake condition:	Non-vegetated
Stability:	Stable
Lake type:	Peat
Maximum depth:	5.1 m

Due to a lack of historic data, the timing of submerged vegetation disappearance from Lake Areare is unknown. A 1991 survey found only a sparse cover of submerged plants at only one of the five sites surveyed and although a recent survey has not been completed for Lake Areare, no improvements are expected due to the high peat staining of the lake water and lack of major land-use changes since 1991.

Table 3: LakeSPI results for Lake Areare.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	95	90	0
Historical data	1991$^{\phi}$	0	0	0
Present day	2003*	0	0	0

$^{\phi}$ Sparse vegetation (cover <10%); * Anticipated score

4.1.2 Lake Hotoananga

Lake condition:	Non-vegetated
Stability:	Stable
Lake type:	Peat
Maximum depth:	3 m

Egeria densa dominated the submerged vegetation of Lake Hotoananga from the late 1950's until the early 1990's and during this period the lake remained in an invaded but stable condition. No submerged plants were found in the 2001 LakeSPI survey despite the adequate water clarity noted by divers at that time.

Table 4: LakeSPI results for Lake Hotoananga.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	97	93	0
Historical data	1958	51	73	56
	1980	31	47	78
	1983	31	47	78
	1991	31	53	78
Present day	2001	0	0	0

4.1.3 Lake Kainui (D)

Lake condition:	Moderate
Stability:	Stable
Lake type:	Peat
Maximum depth:	6.7 m

A strongly coloured peat lake, Lake Kainui is likely to have provided poor habitat for submerged plants in pre-European times as well as historically. It was first investigated by NIWA staff for the presence of submerged vegetation in 1983 and again in 1991 and no submerged plant species were found. The present assessment found that charophytes (*Nitella* aff. *cristata*) have since developed to covers exceeding 10% at three of the sites investigated, and so the lake generated a moderate LakeSPI score. Whether this recent growth will be sustained is not known, but it may reflect reduced humic colour inputs from the adjacent Kainui peat bog in recent times, following drainage, subsidence and carbon loss in the peat soils.

Table 5: LakeSPI results for Lake Kainui (Lake D).

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	95	90	0
Historical data	1983	0	0	0
	1991	0	0	0
Present day	2005	44	28	0

4.1.4 Lake Kaituna (B)

Lake condition:	Non-vegetated
Stability:	Stable
Lake type:	Peat
Maximum depth:	1.3 m

This lake has peat-stained waters and high levels of suspended matter. It was first investigated by NIWA staff in 1992 and no submerged plant species were found. Since then major willow clearance works and native riparian planting have been undertaken in the lake margins, together with land practice methods to reduce nutrient run-off from the surrounding agricultural catchment.

The most recent survey also did not detect submerged vegetation. We conclude that the poor water clarity and disturbance by koi carp currently exclude plant establishment.

Table 6: LakeSPI results for Lake Kaituna.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	94	86	0
Historical data	1992	0	0	0
Present day	2007	0	0	0

4.1.5 Lake Koromatua

Lake condition:	Non-vegetated
Stability:	Stable
Lake type:	Peat
Maximum depth:	1.2 m

Lake Koromatua has peat-stained waters that would have naturally constrained the growth of submerged plants. Until recent times the lake received direct agricultural discharges and was considered hypereutrophic. Water level was also affected by drainage in the area. In 1991 NIWA staff found no submerged plants during a survey of six sites and concluded that poor water clarity and the lakes shallow nature (0.8 m depth) explained their absence. In recent years agricultural inputs have been diverted, the lake level has been raised, willows controlled and native riparian plantings has been made.

The survey in 2007 did not record any submerged plants, again likely due to ongoing poor water clarity.

Table 7: LakeSPI results for Lake Koromatua.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	94	86	0
Historical data	1991	0	0	0
Present day	2007	0	0	0

4.1.6 Lake Mangakaware

Lake condition:	High
Stability:	Improving
Lake type:	Peat
Maximum depth:	4.8 m

A relatively diverse vegetation persists within the lake despite the presence of the invasive weed *Egeria densa* for in excess of fourteen years. The most recent survey suggested a reduced impact by this species and a slight expansion by native plants, although the vegetation remains sparse. The weed *Elodea canadensis* was recorded for the first time during the current survey. This species is generally less invasive than *E. densa*.

Table 8: LakeSPI results for Lake Mangakaware.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	94	87	0
Historical data	1991	25	31	55
Present day	2005	63	65	33

4.1.7 Lake Mangahia

Lake condition:	Non-vegetated
Stability:	Stable
Lake type:	Peat
Maximum depth:	1.5 m

In 1992 no submerged vegetation was recorded and it was considered that the low water clarity due to strong peat staining made conditions unsuitable for plants. The NIWA survey in 2007 again did not record any submerged vegetation. Koi carp were observed in 2008 (NIWA records) and are likely to further reduce the suitability of conditions for submerged vegetation development.

Table 9: LakeSPI results for Lake Mangahia.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	94	86	0
Historical data	1992	0	0	0
Present day	2007	0	0	0

4.1.8 Lake Maratoto

Lake condition:	Non-vegetated
Stability:	Stable
Lake type:	Peat
Maximum depth:	7.1 m

No submerged plants have been recorded previously, although investigations by NIWA staff were made at five sites in 1991. The 2009 survey also found submerged vegetation to be absent.

Table 10: LakeSPI results for Lake Maratoto.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	90	81	0
Historical data	1992	0	0	0
Present day	2009	0	0	0

4.1.9 Lake Milicich

Lake condition:	Non-vegetated
Stability:	-
Lake type:	Peat
Maximum depth:	2.2 m

Visited for the first time in 2009, the submerged vegetation was restricted to floating fragments of the alien bladderwort *Utricularia gibba* at some sites, but at covers that did not exceed the 10% required for generating a LakeSPI score. *U. gibba* is a recent invader in the Waikato Region and its performance and likely impacts on future LakeSPI assessments of the regions lakes is not known.

Table 11: LakeSPI results for Lake Milicich.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	97	93	0
Present day	2009	0	0	0

4.1.10 Lake Ngaroto

Lake condition:	Non-vegetated
Stability:	Stable
Lake type:	Peat
Maximum depth:	4 m

Lake Ngaroto has a history of submerged weed problems with *Elodea canadensis* and *Ceratophyllum demersum* first identified from the lake in 1968-1969 (Champion et al. 1993). LakeSPI results for historical data show that the lake remained in a degraded and highly impacted condition until a further decline in the presence of native vegetation was noted in the 1984 survey, resulting in a LakeSPI index of only 14%. By 1992, no submerged vegetation was found in Lake Ngaroto and a visit to the lake in March 2003, showed no evidence of submerged plants.

Table 12: LakeSPI results for Lake Ngaroto.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	97	93	0
Historical data	1977	23	47	89
	1981	34	53	70
	1984	14	7	85
	1992	0	0	0
Present day	2003	0	0	0

4.1.11 Lake Pataka

Lake condition:	Non-vegetated
Stability:	Stable
Lake type:	Peat
Maximum depth:	5 m

Scattered plants of the native charophyte, *Nitella* aff. *cristata*, were found where shallow habitat (0.5-0.7 m) was available. Much of the rest of the margins comprised floating sudds of marginal plants or *Typha orientalis* that extended to over 0.7 m depth. Low water clarity, including high levels of peat-staining, would restrict the depth extent of submerged plants.

Submerged vegetation development is currently insufficient to apply the LakeSPI method and a default value of 0 is scored. This is largely unchanged from previous surveys (Champion et al. 1993). However, initiatives observed in 2007, including marginal fencing and riparian plantings, may improve water quality and habitat for submerged plants.

Table 13: LakeSPI results for Lake Pataka.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	85	70	0
Historical data	1977	0	0	0
	1992	0	0	0
Present day	2007	0	0	0

4.1.12 Lake Posa

Lake condition:	Non-vegetated
Stability:	Stable
Lake type:	Peat
Maximum depth:	4 m

No submerged vegetation was found, probably on account of the thick marginal sudds of plants that extended out over open water to depths of up to 2 m, and the low water clarity. This resembles descriptions from earlier surveys (Champion et al. 1993). A substantial increase in water clarity would be necessary for any widespread development of submerged vegetation, given the current extent of floating marginal sudd.

Table 14: LakeSPI results for Lake Posa.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	91	80	0
Historical data	1977	0	0	0
	1992	0	0	0
Present day	2007	0	0	0

4.1.13 Lake Rotokauri

Lake condition:	Non-vegetated
Stability:	Stable
Lake type:	Peat
Maximum depth:	4 m

LakeSPI indices show lake condition declining in Lake Rotokauri from the time of the first survey (1977) until the present day. It is likely that *Egeria densa* invaded the lake in the 1970s with the first record confirmed in 1977 (Chapman & Boubée 1977). By 1979 it had become well established around the lake and dominated the submerged vegetation (J. Clayton pers obs). In 1991, dense *E. densa* weed beds still dominated the lake (Champion et al. 1993), and native vegetation (Native Condition Index) and overall LakeSPI scores had declined. *E. densa* weed beds were observed to decline in 1996/97 (Warr 1998) and from 1997 to 2002 the lake was described as turbid and dominated by phytoplankton (Barnes 2002). Vegetation recovery is unlikely given the hypertrophic status of this lake.

Table 15: LakeSPI results for Lake Rotokauri.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	97	93	0
Historical data	1977	34	33	67
	1979	20	20	85
	1989	23	27	85
	1990	11	0	93
	1991	14	7	93
Present day	2003*	0	0	0

* Anticipated score

4.1.14 Lake Rotokawau

Lake condition:	Non-vegetated
Stability:	Stable
Lake type:	Peat
Maximum depth:	1.2 m

LakeSPI results document a deteriorating lake condition with the most recent surveys (1992 and 2007) giving a default LakeSPI score of 0. In pre-European times it is likely that Lake Rotokawau had extensive submerged vegetation, although this would not have been as diverse as that recorded for adjacent Lake Waikere in the 1870's on account of smaller size and peat influenced waters. Submerged vegetation persisted until the mid 1980's, after the plant collapse in Lake Waikere, although it was noted to be seasonal, dying back in winter (Champion et al. 1993). Despite this vegetation instability, the lake was still dominated by native plants, possibly as they were better suited to summer recovery from seed banks than the vegetatively reproducing weed *Egeria densa*.

Table 16: LakeSPI results for Lake Rotokawau.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	94	86	0
Historical data	1983-84	53	71	48
	1992	0	0	0
Present day	2007	0	0	0

4.1.15 Lake Rotomanuka

Lake condition:	Non-vegetated
Stability:	Stable
Lake type:	Peat
Maximum depth:	8.7 m

Egeria densa was likely to have been introduced prior to 1977, when an oxygen weed was first reported (Champion et al. 1993). By 1983 *E. densa* had reached its full potential in Lake Rotomanuka as indicated by a LakeSPI Invasive Impact Index of greater than 90% and native plant species were found in small shallow pockets only. Water clarity records indicated that submerged plants were likely stressed by inadequate light conditions over 1996 to 1998 (de Winton 2003). The more recent LakeSPI surveys found sparse submerged plants in Lake Rotomanuka that did not exceed the threshold for generating a LakeSPI score.

Table 17: LakeSPI results for Lake Rotomanuka.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	95	90	0
Historical data	1977	41	52	78
	1983	15	4	93
	1991	15	4	93
	2001	0	0	0
Present day	2007	0	0	0

4.1.16 Lake Rotoroa (Hamilton)

Lake condition:	High
Stability:	Declining
Lake type:	Peat
Maximum depth:	6 m

Lake Rotoroa provides an interesting array of LakeSPI indices as the lake has a detailed history of invasive weed problems followed by vegetation decline, a period of without submerged vegetation, followed by the recovery of a charophyte community. However, the spread of *Egeria densa* since being re-recorded in November 2002 is beginning to impact upon lake condition and is likely to cause further deterioration in the future.

Table 18: LakeSPI results for Lake Rotoroa.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	95	90	0
Historical data	1981	30	40	74
	1984	35	40	74
	1986	38	40	74
	1989	35	40	67
	1990	0	0	0
	1999	0	0	0
	2000	73	45	0
	2001	73	45	0
	2002 Feb	75	50	0
	2002 Nov	70	50	7
	2003	75	50	0
Present day	2009	52	50	37

4.1.17 Lake Ruatuna

Lake condition:	Non-vegetated
Stability:	Stable
Lake type:	Peat
Maximum depth:	3.2 m

No plants were found, similar to previous investigations (Champion et al. 1993), and so the lake scores a default of 0. We noted large numbers of empty mussel shells on the lake bed at several sites, but no live mussels were found. This is further indication that the lake was in a better condition in the recent past. Currently, the low water clarity appears the main factor preventing submerged plant development, but the presence of a dead rudd also confirms a population of the herbivorous fish that elsewhere are proven to retard submerged vegetation recovery.

Table 19: LakeSPI results for Lake Ruatuna.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	94	87	0
Historical data	1977	0	0	0
	1992	0	0	0
Present day	2007	0	0	0

4.1.18 Lake Serpentine East (Rotopiko East)

Lake condition:	Excellent
Stability:	Stable
Lake type:	Peat
Maximum depth:	4.4 m

Lake Serpentine East together with Lake Serpentine North currently represent the highest scoring lakes in the Waikato Region with a LakeSPI Index of ≥90%, being one of the only remaining Waikato lakes to remain un-impacted by invasive plant species. The high score is driven by presence of well developed, solely native vegetation, dominated by pondweeds (*Potamogeton* spp.) and charophytes. Lake Serpentine East currently has a LakeSPI Index of 91% indicating that it is still close to its maximum scoring potential. The recent record of the introduced bladderwort, *Utricularia gibba*, at adjacent Lake Serpentine South, represents a possible threat to the native character of this lake and also to the North Lake. Spread by waterfowl, it is likely to be introduced to many lakes in the Waikato Region over time.

Table 20: LakeSPI results for Lake Serpentine East.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	97	93	0
Historical data	1977	89	73	0
	1991	89	73	0
	2001	91	80	0
	2002	91	80	0
	2003	89	73	0
	2005	90	76	0
	2007	91	80	0
	2008	91	78	0
Present day	2009	91	79	0

4.1.19 Lake Serpentine North (Rotopiko North)

Lake condition:	Excellent
Stability:	Stable
Lake type:	Peat
Maximum depth:	4 m

Lake Serpentine North together with Lake Serpentine East currently represents the highest scoring lakes in the Waikato Region with a LakeSPI Index of ≥90%. Lake Serpentine North differs from Lake Serpentine East in that it has greater coverage of plants, mostly charophytes, often down to a greater depth. Although LakeSPI indices show excellent lake condition, the submerged vegetation is under stress (e.g., epiphytic burden, fish grazing, fluctuating depth limit for charophyte meadows) and there is a risk of major plant decline. The likely introduction of *Utricularia gibba* presents another potential impact on future lake condition.

Table 21: LakeSPI results for Lake Serpentine North.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	97	93	0
Historical data	1977	91	80	0
	1991	86	67	0
	2001	94	87	0
	2003	91	80	0
	2005	90	77	0
	2007	93	83	0
	2008	90	76	0
Present day	2009	89	75	0

4.1.20 Lake Serpentine South (Rotopiko South)

Lake condition:	Non-vegetated
Stability:	Declining
Lake type:	Peat
Maximum depth:	3.6 m

A survey of Lake Serpentine South in 1991 found only sparse native submerged vegetation, of low species diversity, that did not exceed the 10% plant cover required to generate a LakeSPI score. Over 2005 to 2007 an expansion in the cover of the native pondweed meant the lake scored a relatively high LakeSPI Index value of 86%. However, this development was not sustained and more recently in 2009 vegetation cover was again below the threshold for LakeSPI. This reduction in cover exceeded expected seasonal variations that are commonly observed for pondweeds and indicates the lake is on the cusp between a vegetated and de-vegetated state. The recent record of the introduced bladderwort *Utricularia gibba* at this site is the first for lakes of the Waikato Region.

Table 22: LakeSPI results for Lake Serpentine South.

State	Year	LakeSPI Index (%)	Native Plant Index (%)	Invasive Plant Index (%)
Pristine	1800s	97	93	0
Historical data	1991$^{\phi}$	0	0	0
	2005‡	70	67	0
	2007	86	68	0
	2008	86	68	0
Present day	2009$^{\phi}$	0	0	0

$^{\phi}$ Sparse vegetation (cover <10%); ‡ Based on four sites where plant cover exceeded 10%.

4.1.21 Lake Tunawhakapeka (E)

Lake condition:	Non-vegetated
Stability:	Stable
Lake type:	Peat
Maximum depth:	1 m

Water level was low at the time of the 2007 survey (most sites <0.5 m). As a shallow lake, it is very likely to have supported extensive submerged vegetation in pre-European times. It is currently de-vegetated and so scores a default LakeSPI score of 0%. The sole record of one rooted plant was the introduced pondweed, *Potamogeton crispus*, which is spread as seed by waterfowl.

Table 23: LakeSPI results for Lake Tunawhakapeka (E).

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	91	79	0
Historical data	1991	0	0	0
Present day	2007	0	0	0

4.2 Riverine Lakes

The Waikato Region's nine riverine lakes are part of an extensive wetland system that includes Lakes Whangape, Waahi, Waikare and the internationally important Whangamarino Wetland. All of the riverine lakes are naturally shallow (<5m depth) and exposed, which, following the collapse of submerged vegetation has acted to stabilise them in a highly turbid condition. Of the nine riverine lakes surveyed for this report none of the lakes contained submerged vegetation exceeding covers required for LakeSPI assessment.

Figure 6: Location of Riverine lakes within the Waikato Region with assessed lakes shown in white type (source – Environment Waikato)**.**

Table 24: Summary of LakeSPI indices for the Waikato riverine lakes in order of their overall lake condition.

Lake	LakeSPI Index (%)	Native Condition Index (%)	Invasive Condition Index (%)
Hakanoa	0	0	0
Kimihia	0	0	0
Ohinewai	0	0	0
Okowhao	0	0	0
Rotongaro	0	0	0
Rotongaroiti	0	0	0
Waahi	0	0	0
Waikare	0	0	0
Whangape	0	0	0

4.2.1 Lake Hakanoa

Lake condition:	Non-vegetated
Stability:	Stable
Lake type:	Riverine
Maximum depth:	2.5 m

Surface reaching weed beds of *Egeria densa*, were noted in Lake Hakanoa prior to the 1970's, and by 1973 lake condition had declined resulting in a LakeSPI Index of only 12%. Lake condition continued to decline after 1973 and it is likely that further declining water quality and herbicide applications for weed control resulted in a vegetation collapse shortly afterwards (Champion et al. 1993). Although the lake has not been recently surveyed it is expected to remain de-vegetated.

Table 25: LakeSPI results for Lake Hakanoa.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	97	93	0
Historical data	1973	12	7	89
	1991	0	0	0
Present day	2003*	0	0	0

* Anticipated score

4.2.2 Lake Kimihia

Lake condition:	Non-vegetated
Stability:	Stable
Lake type:	Riverine
Maximum depth:	3.3 m

In 1958 Mason and Moar collected *Egeria densa* from Lake Kimihia, and suggested this infestation was the primary source for *E. densa* spread through the Waikato River system (Mason 1960). LakeSPI results show lake condition continued to decline from then and by 1991, no submerged vegetation remained in Lake Kimihia. Continuing high levels of turbidity make it unlikely that the status of this lake has changed in recent years.

Table 26: LakeSPI results for Lake Kimihia.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	97	93	0
Historical data	1975	26	43	86
	1980	21	0	78
	1991	0	0	0
Present day	2003*	0	0	0

* Anticipated score

4.2.3 Lake Ohinewai

Lake condition:	Non-vegetated
Stability:	Stable
Lake type:	Riverine
Maximum depth:	4.5 m

During a survey of Lake Ohinewai in 1981, *Egeria densa* was recorded as covering over 80% of the lake bottom (WVA, 1981). LakeSPI results show lake condition continued to decline from then, and by 1991 no submerged vegetation remained. Today Lake Ohinewai remains de-vegetated.

Table 27: LakeSPI results for Lake Ohinewai.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	97	93	0
Historical data	1958	97	93	0
	1981	26	27	85
	1983	11	0	93
	1991	0	0	0
Present day	2008	0	0	0

4.2.4 Lake Okowhao

Lake condition:	Non-vegetated
Stability:	Stable
Lake type:	Riverine
Maximum depth:	2.2 m

This lake is now de-vegetated following a period of dominance by the invasive weed *Egeria densa* from at least 1981 to 1991. The most recent 2009 survey found no submerged plant species.

Table 28: LakeSPI results for Lake Okowhao.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	94	86	0
Historical data	1986	16	11	87
	1991	24	14	78
	2005	0	0	0
Present day	2009	0	0	0

4.2.5 Lake Rotongaro

Lake condition:	Non-vegetated
Stability:	Stable
Lake type:	Riverine
Maximum depth:	3.3 m

Lake Rotongaro is presently de-vegetated and turbid and koi carp are present. Previously it was known to support variable beds of the invasive weed, *Egeria densa*, as well as native turf communities and occasional beds of charophytes. The pre-European lake condition would have been similar to the other large, riverine water bodies described by Kirk (1871).

Table 29: LakeSPI results for Lake Rotongaro.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	100	100	0
Historical data	1986	73	72	22
	1991	30	28	71
Present day	2005	0	0	0

4.2.6 Lake Rotongaroiti

Lake condition:	Non-vegetated
Stability:	Stable
Lake type:	Riverine
Maximum depth:	0.5 m

Egeria densa was most likely introduced into Lake Rotongaroiti in the early 1960's (Champion et al. 1993). A survey completed in 1986 found native plant species still growing amongst invasive species although all plants formed sparse covers. In 1992, most of the previous vegetation had been lost and today the lake remains in a de-vegetated state, with koi carp present.

Table 30: LakeSPI results for Lake Rotongaroiti.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	97	93	0
Historical data	1986	56	67	41
	1992[ϕ]	0	0	0
Present day	2005	0	0	0

[ϕ] Sparse vegetation (cover <10%)

4.2.7 Lake Waahi

Lake condition:	Non-vegetated
Stability:	Stable
Lake type:	Riverine
Maximum depth:	5 m

Aquatic vegetation in Lake Waahi has undergone major changes in species composition and abundance since 1870 when first records were made by Kirk (1871). Kirk's 1870 description for this lake noted "more copious vegetation" than Lakes Whangape and Waikere. By the late 1930s & 1940s local residents noted extensive weed beds, which prevailed until the late 1970s (Clayton & de Winton 1989), with *Egeria densa* dominating in the latter years. During the late 1970s a major decline occurred in the submerged aquatic vegetation and the lake has remained predominantly devegetated ever since.

Table 31: LakeSPI results for Lake Waahi.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	100	100	0
Historical data	1976	18	5	85
Present day	2005	0	0	0

4.2.8 Lake Waikare

Lake condition:	Non-vegetated
Stability:	Stable
Lake type:	Riverine
Maximum depth:	2 m

Early historic investigations of Lake Waikare by Kirk (1871) suggest that the lake was in 'pristine' condition, resulting in a LakeSPI Index of 100%. By 1978 (>100 years later), the LakeSPI Index had dropped to 24% and the invasive weed species, *Egeria densa* was having a marked impact. Water level changes, turbid waters and pest fish are likely to have been contributing factors to a weed bed collapse in the late 1970's/early 1980's (Champion et al. 1993). Presently Lake Waikare supports no submerged vegetation.

Table 32: LakeSPI results for Lake Waikare.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	100	100	0
Historical data	1871	100	100	0
	1978	24	29	85
	1984	0	0	0
	1992	0	0	0
	1993	0	0	0
	2001	0	0	0
Present day	2008	0	0	0

4.2.9 Lake Whangape

Lake condition:	Non-vegetated
Stability:	Stable
Lake type:	Riverine
Maximum depth:	2.7 m

Today, Lake Whangape remains in a highly impacted condition with a LakeSPI Index of 0%. Previously the invasive weed species *Ceratophyllum demersum*, which is ranked the worst submerged weed in New Zealand, was having a major impact on the lake, but weed beds have now crashed leaving the lake de-vegetated. The pristine state, close to that described by Kirk (1871), would have comprised a diverse vegetation, extending across the entire bed of the lake.

Table 33: LakeSPI results for Lake Whangape.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	100	100	0
Historical data	1869	100	100	0
	1958	26	29	81
	1982	24	21	81
	1991	9	0	93
	2001	3	0	100
Present day	2005	0	0	0

4.3 Taupo Volcanic Zone Lakes

Lake Taupo, New Zealand's largest lake was created by a series of volcanic eruptions leaving a giant crater nearly 2000 years ago. Taupo, although the largest and most well known is just one of the six volcanic zone lakes in the Waikato region surveyed for this report. All six of the volcanic lakes contain a mixed assemblage of native and invasive aquatic plant species.

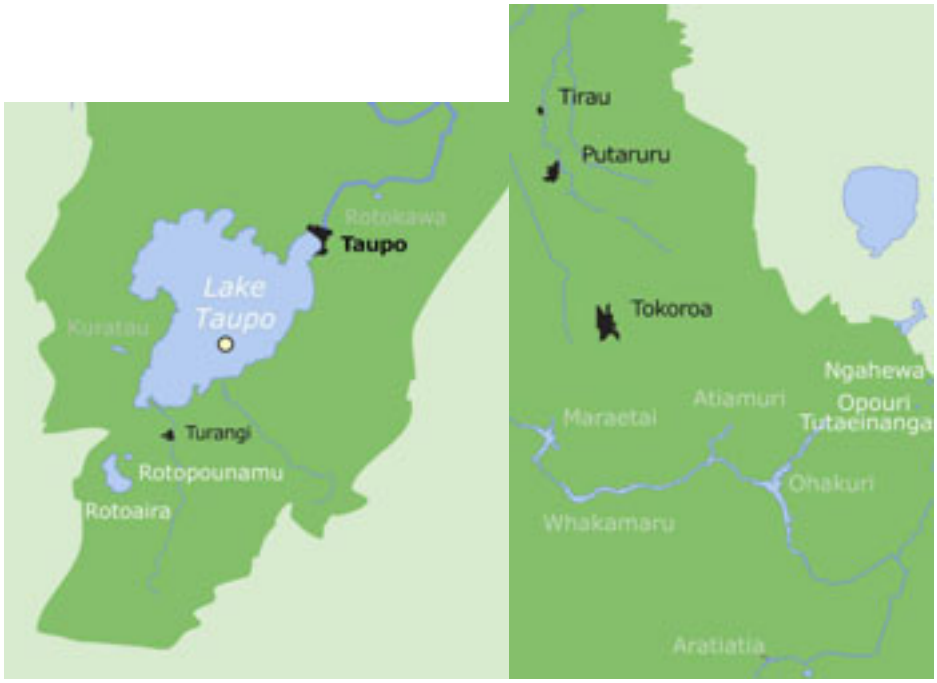


Figure 7: Location of Taupo volcanic zone lakes within the Waikato Region with assessed lakes shown in white type (source – Environment Waikato).

Table 34: Summary of LakeSPI indices for the Taupo volcanic zone lakes in order of their current lake condition.

Lake	LakeSPI Index (%)	Native Condition Index (%)	Invasive Condition Index (%)
Rotopounamu	71	43	0
Opouri	58	33	4.4
Taupo	36	47	78
Ngahewa	29	26	67
Rotoaira	23	27	90
Tutaeinanga	0	0	0

4.3.1 Lake Ngahewa

Lake condition:	Poor
Stability:	Improving
Lake type:	Volcanic
Maximum depth:	7.5 m

Since being listed as essentially de-vegetated in 2004, submerged vegetation in Lake Ngahewa has made a partial recovery and now exceeds a 10% cover making it possible to generate a LakeSPI score. Although the presence of *Lagarosiphon major* has resulted in a moderately high Invasive Impact score, this invasive presence is still considered preferable to a de-vegetated state.

Table 35: LakeSPI results for Lake Ngahewa.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	90	81	0
Historical data	1973	78	57	0
	1989	15	5	81
	2004	0	0	0
Present day	2008	29	26	67

4.3.2 Lake Opouri

Lake condition:	High
Stability:	Improving
Lake type:	Volcanic
Maximum depth:	25 m

The lake retains moderate plant biodiversity, with the only invasive weed, *Elodea canadensis*, being of low occurrence and cover during the present assessment. Comparing the recent assessment with surveys made in the 1980's showed there was a reduction in charophytes, a 2 m decrease in vegetation depth extent and a large reduction in invasive impact by *E. canadensis*. While the Native Condition Index remained similar over the 20 years, the Invasive Impact Index dropped, leading to a higher LakeSPI score in 2004. This lake vegetation appears to have similarities to nearby Lake Okaro, where lake anoxia has apparently caused root death and detachment of *E. canadensis* shoots at various intervals (Clayton et al. 2005).

Table 36: LakeSPI results for Lake Opouri.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	88	80	0
Historical data	1984	34	30	54
	1989	30	23	62
Present day	2004	58	33	4

4.3.3 Lake Rotoaira

Lake condition:	Moderate
Stability:	Declining
Lake type:	Volcanic
Maximum depth:	14.6 m

LakeSPI scores show the overall condition of Lake Rotoaira declining from the impact of invasive weed species. In 1979 invasive weeds (*Elodea canadensis*, *Potamogeton crispus* and *Ranunculus trichophyllus*) had a moderate impact on the LakeSPI score. *Lagarosiphon major* and *Ceratophyllum demersum* were introduced into the lake in the 1980's and 90's (respectively) and resulted in a further large increase in the Invasive Impact Index and reduction in LakeSPI score. Since then, while further invasive impact has been small, the Native Condition Index has decreased more substantially due to the partial loss of deeper native charophyte meadows. Other elements of native vegetation remain, such as the species-rich turfs found at moderately exposed shorelines.

Table 37: LakeSPI results for Lake Rotoaira.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	100	100	0
Historical data	1979	51	68	67
	1999	32	46	83
	2003	27	39	86
Present day	2007	23	27	90

4.3.4 Lake Rotopounamu

Lake condition:	High
Stability:	Stable
Lake type:	Volcanic
Maximum depth:	7.9 m

Lake Rotopounamu is a high altitude (705 m) isolated lake in a forested catchment that lacks some common components of the submerged flora and invertebrates (e.g., mussels). Despite this, the lake had a historically high LakeSPI Index of 88% (1981) reflecting the extensive charophyte meadows that were present until at least 1990 (NIWA unpub. records). Since then, there has been a reduction in the LakeSPI Index to 71%, driven by a decline in native plant representation due to loss of charophyte meadows. This change may be due to geothermal activity, volcanic ash falls, or a landslide, as plant remnants during the recent survey were found buried under a layer of silt. The lake still scores highly as emergent and turf communities extend to a modest depth, while invasive submerged weeds are absent. Other observations included the presence of exotic marginal species, *Juncus bulbosus* and *Ranunculus flammula*, which are unlikely to be invasive.

Table 38: LakeSPI results for Lake Rotopounamu.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	88	76	0
Historical data	1981	88	76	0
Present day	2004	71	43	0

4.3.5 Lake Taupo

Lake condition:	Moderate
Stability:	Declining
Lake type:	Volcanic
Maximum depth:	162.8 m

Elodea canadensis and *Lagarosiphon major* have been present in Lake Taupo since the 1960's and *Ceratophyllum demersum* was first recorded in Lake Taupo in 1980 (Howard-Williams and Davies 1980). Since then, *C. demersum* has progressively impacted upon lake condition. The ability of this species to occupy deep water and displace charophyte meadows means that future LakeSPI scores are likely to decline further. This lake would benefit from an updated assessment and further attention to establishing suitable baseline sites, given the size and diversity of the lake.

Table 39: LakeSPI results for Lake Taupo.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	100	100	0
Historical data	1977	54	67	59
	1991	54	67	59
Present day*	2002	36	47	78

*Results are indicative only

4.3.6 Lake Tutaeinanga

Lake condition:	Non-vegetated
Stability:	Declining
Lake type:	Volcanic
Maximum depth:	11 m

The submerged vegetation in Lake Tutaeinanga has decreased significantly since being last surveyed in 2004 and it is now essentially de-vegetated. Occasional shoots of *Egeria densa* and *Potamogeton ochreatus* still persist but as covers do not exceed 10% at all but one site this lake now fails to generate a LakeSPI Index.

Table 40: LakeSPI results for Lake Tutaeinanga.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	94	87	0
Historical data	2004	52	35	23
Present day	2008	0	0	0

4.4 Waikato Hydro Lakes

Eight hydro lakes today form part of the natural environment along the Waikato River between Lake Taupo and Cambridge below the bottom dam (Figure 8). The first two hydro electric dams were built in 1929 and 1947, Arapuni and Karapiro respectively. Soon after six more hydro lakes followed all completed in the 1950's (Maraetai 1952, Whakamaru 1956, Atiamuri 1958) and 1960's (Ohakuri & Waipapa 1961, Aratiatia 1964).

Figure 8: Location of Waikato River hydro lakes assessed in this report (source – Environment Waikato).

Early records show New Zealand's worst ranked invasive weed species *Ceratophyllum demersum* first appeared in the upper Waikato River soon after completion of the hydro lakes in 1963 (Schwarz et al. 1999). *C. demersum* spread quickly down through the hydro lakes and dominated the upper reaches of Lake Karapiro by 1972. Today dense weed beds of *C. demersum* dominate the submerged

vegetation in seven of the eight Waikato River hydro lakes resulting in some of highest Invasive Impact scores generated so far in this report.

Lake Hinemaimaia B has also been included in this section of the report as it is a damned watercourse on the Hinemaimaia Stream east of Lake Taupo.

Table 41: Summary of LakeSPI indices for the hydro lakes in order of their current lake condition.

Lake	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Aratiatia	27	39	84
Ohakuri	14	10	96
Arapuni	12	10	97
Waipapa	12	9	96
Atiamuri	11	3	99
Whakamaru	10	8	96
Maraetai	9	3	97
Karapiro	9	3	97
Hinemaimaia B	0	0	0

4.4.1 Lake Arapuni

Lake condition:	Poor
Stability:	-
Lake type:	Hydro
Maximum depth:	49 m

Lake Arapuni is the seventh hydro lake downstream of Taupo. Like most of the Waikato hydro lakes, *Ceratophyllum demersum* dominates the submerged vegetation with weed beds recorded to a depth of 9 m. A low Native Condition Index reflects the presence of submerged turf species recorded at four of five of the sites surveyed.

Table 42: LakeSPI results for Lake Arapuni.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Potential condition		96	93	0
Present day	2009	12	9	97

4.4.2 Lake Aratiatia

Lake condition: Moderate

Stability: -

Lake type: Hydro

Maximum depth: 11 m

Lake Aratiatia is the first hydro lake downstream of Taupo and is the only Waikato River hydro lake that still supports native submerged plant communities at most of the sites surveyed, resulting in a moderate Native Condition Index. Invasive weed beds were prominent at all sites with *Egeria densa* being the dominant invasive species at the time of this survey.

Table 43: LakeSPI results for Lake Aratiatia.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Potential condition		95	92	0
Present day	2009	27	39	84

4.4.3 Lake Atiamuri

Lake condition: Poor

Stability: -

Lake type: Hydro

Maximum depth: 31 m

The third hydro lake downstream of Taupo, Lake Atiamuri has tall, dense weed beds of *Ceratophyllum demersum* and *Egeria densa* recorded down to a depth of 12 m. This high level of impact by invasive species has resulted in the highest Invasive Impact Index of 99% for any lake in this report.

Table 44: LakeSPI results for Lake Atiamuri.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Potential condition		96	93	0
Present day	2009	12	3	99

4.4.4 Lake Hinemaiaia (B)

Lake condition:	Non-vegetated
Stability:	Declining
Lake type:	Hydro
Maximum depth:	15 m

Hinemaimaia (B) is the lower of three dammed water bodies in a hydro-scheme constructed from 1939. It currently supports a low and patchy vegetation cover and is a poor environment for plant growth due to sediment instability, occasional turbid flows and frequent disturbance.

Table 45: LakeSPI results for Lake Hinemaiaia (B).

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Potential condition		96	93	0
Historic	1982	45	37	41
Present day	2005	0	0	0

4.4.5 Lake Karapiro

Lake condition:	Poor
Stability:	Stable
Lake type:	Hydro
Maximum depth:	34 m

Lake Karapiro is the eighth and final Waikato hydro lake downstream of Taupo and is solely dominated by *Ceratopyllum demersum*. Invasive weed problems within Lake Karapiro have been in the spotlight of recent years with extensive annual weed control (up to 100 ha) currently being carried out during autumn in preparation for the World Rowing Championships on this lake in 2010. The extremely high invasive impact on the lake by *C. demersum* and the lack of native plant species has resulted in Lake Karapiro generating one of the lowest LakeSPI scores (equal with Lake Maraetai) in this report.

Table 46: LakeSPI results for Lake Karapiro.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Potential condition		96	93	0
Historic	2001	10	5	92
Present day	2009	9	3	97

4.4.6 Lake Maraetai

Lake condition:	Poor
Stability:	Stable
Lake type:	Hydro
Maximum depth:	68 m

The fifth hydro lake downstream of Taupo, Lake Maraetai is dominated by dense weed beds of *Ceratophyllum demersum* and this has resulted in it generating one of our lowest LakeSPI scores (equal with Lake Karapiro) recorded for any of the Waikato lakes so far surveyed in this report. *C. demersum* and *Egeria densa* have been present in Lake Maraetai since at least 1966 but at that time the less invasive *Elodea canadensis* would have been the dominating species (Gibbs and Wilson 1966).

Table 47: LakeSPI results for Lake Maraetai.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Potential condition		96	93	0
Historic	2008	8	1	99
Present day	2009	9	3	97

4.4.7 Lake Ohakuri

Lake condition: Poor

Stability: -

Lake type: Hydro

Maximum depth: 40 m

Lake Ohakuri is the second hydro lake downstream of Taupo and was the first of the Waikato hydro lakes to record the presence of *Ceratophyllum demersum* in 1963 (Gibbs and Wilson 1966, Widgery 1966). Today *C. demersum* continues to dominate the vegetation forming dense weed beds to a depth of 10 m.

Table 48: LakeSPI results for Lake Ohakuri.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Potential condition		96	93	0
Present day	2009	14	9	96

4.4.8 Lake Waipapa

Lake condition:	Poor
Stability:	-
Lake type:	Volcanic
Maximum depth:	22 m

The sixth hydro lake downstream of Taupo, the submerged vegetation of Lake Waipapa remains dominated by invasive species *Ceratophyllum demersum* and *Egeria densa*. A low Native Condition score has been generated on account of three of the five sites recording the presence of a submerged turf community.

Table 49: LakeSPI results for Lake Waipapa.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Potential condition		96	93	0
Present day	2009	12	9	96

4.4.9 Lake Whakamaru

Lake condition: Poor

Stability: -

Lake type: Hydro

Maximum depth: 36 m

Lake Whakamaru is the fourth hydro lake downstream of Taupo and is dominated by weed beds of *Ceratophyllum demersum*. A low Native Condition score has been generated on account of low cover turf species being recorded at most sites.

Table 50: LakeSPI results for Lake Whakamaru.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Potential condition		96	93	0
Present day	2009	10	8	96

4.5 West Coast Sand Dune Lakes

Seven sand dune lakes located along the West Coast of the Waikato Region have been surveyed for this report. All these lakes were found to support submerged vegetation.

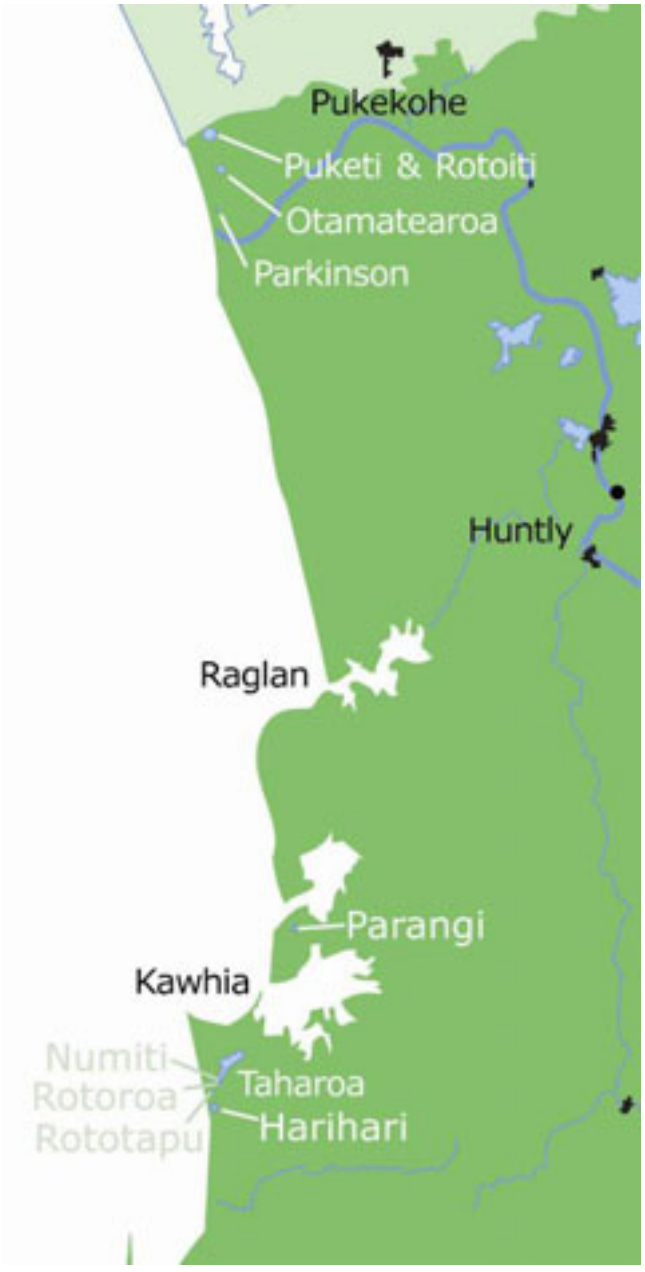


Figure 9: Location of West Coast sand dune lakes within the Waikato Region with assessed lakes shown in white type (source – Environment Waikato).

Table 51: Summary of LakeSPI indices for the West Coast sand dune lakes in order of their current lake condition.

Lake	LakeSPI Index (%)	Native Condition Index (%)	Invasive Condition Index (%)
Harihari	45	59	65
Taharoa	39	46	63
Parkinson	28	35	82
Rotoiti	23	25	84
Parangi	22	11	75
Puketi	21	18	85
Otamatearoa	18	29	96

4.5.1 Lake Harihari

Lake condition:	Moderate
Stability:	Stable
Lake type:	Dune
Maximum depth:	8 m

There is no historical vegetation data for Lake Harihari, but recent assessments are similar, suggesting the lake is relatively stable. During the current assessment, *Elodea canadensis* was widespread but did not dominate the vegetation and a rich assemblage of native plants was present. Other invasive species *Potamogeton crispus* and *Juncus bulbosus* were uncommon, and probably originated from seed introduced via wildfowl.

Table 52: LakeSPI results for Lake Harihari.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	93	86	0
Historic	2005	50	61	58
Present day	2009	45	59	65

4.5.2 Lake Otamatearoa

Lake condition:	Poor
Stability:	Stable
Lake type:	Dune
Maximum depth:	5 m

The low present day LakeSPI Index reflects the presence of *Ceratophyllum demersum,* the most invasive weed, which was introduced some time after 1996. Limited areas still supported remnant charophytes and the invasive species *Elodea canadensis*, which has been present since at least 1950 (Cunningham et al. 1953). Also observed were the threatened plants *Myriophyllum robustum*, *Ranunculus macropus* and *Utricularia australis* amongst the emergent vegetation around the lake margin.

Table 53: LakeSPI results for Lake Otamatearoa.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	97	93	0
Historical data	1950	34	40	70
	1996	39	43	67
	2004	23	43	90
Present day	2009	18	29	96

4.5.3 Lake Parangi

Lake condition:	Moderate
Stability:	-
Lake type:	Dune
Maximum depth:	17.6 m

Elodea canadensis formed an invasive weed bed around the lake to a maximum depth of 3.6 m while native species *Potamogeton ochreatus* and *Myriophyllum triphyllum* are also present and contributed to a moderate LakeSPI Index. There are no historical vegetation data available for Lake Parangi therefore we can draw no conclusions about lake stability.

Table 54: LakeSPI results for Lake Parangi.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	94	89	0
Present day	2008	22	11	75

4.5.4 Lake Parkinson

Lake condition:	Moderate
Stability:	Declining
Lake type:	Dune
Maximum depth:	8 m

This lake has been re-invaded by the exotic weed *Egeria densa* since 1996, which now dominates the vegetation although a narrow fringe of charophytes was sometimes present beyond the main depth extent of weed beds. Previously (1976-1981), the lake was the subject of a successful restoration project, which involved the removal of *E. densa* through stocking of grass carp, followed by netting and rotenone removal of exotic fish. Re-establishment by extensive native vegetation was documented within 5 years of grass carp removal (Tanner et al. 1990a). LakeSPI scores calculated at this time (1986-87) are close to the estimated pristine condition, but with the re-introduction of *E. densa*, LakeSPI scores have once again declined.

Table 55: LakeSPI results for Lake Parkinson.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	93	86	0
Historical data	1976	16	7.9	86
	1986	81	63	0
	1987	83	67	0
Present day	2004	28	35	82

4.5.5 Lake Puketi

Lake condition:	Moderate
Stability:	Stable
Lake type:	Dune
Maximum depth:	7 m

This lake has been dominated by the invasive weed *Egeria densa* for at least 17 years and the LakeSPI Index of 21% is reduced by the high Invasive Impact Index. Previously, the lake is likely to have supported charophyte dominated vegetation, as described in neighbouring Thompson's Lake (Lake Whatihua) by Cunningham et al. (1953). The dominance by *E. densa* and stressful conditions observed for submerged vegetation (e.g., epiphytic burdens) suggested the lake may be at risk of a vegetation decline.

Table 56: LakeSPI results for Lake Puketi.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	93	86	0
Historical data	1950†	83	67	0
	1997	17	0	78
Present day	2004	21	18	85

† Estimated from description of adjacent Thompsons Lake (Whatihua) by Cunningham et al. (1953).

4.5.6 Lake Rotoiti

Lake condition:	Moderate
Stability:	Stable
Lake type:	Dune
Maximum depth:	7 m

The invasive weed, *Egeria densa*, is the dominant plant in Lake Rotoiti and has been for at least 17 years. Prior to this the lake is likely to have supported charophyte dominated vegetation similar to that described in neighbouring Thompsons Lake by Cunningham et al. (1953).

Table 57: LakeSPI results for Lake Rotoiti.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	93	86	0
Historical data	1950[†]	88	76	0
	1987	15	0	85
Present day	2004	23	25	84

[†] Estimated from description of adjacent Thompsons Lake (Whatihua) by Cunningham et al. 1953.

4.5.7 Lake Taharoa

Lake condition:	Moderate
Stability:	Declining
Lake type:	Dune
Maximum depth:	9.2 m

Invasive weed species, *Lagarosiphon major* and *Elodea canadensis,* have had a marked impact on the native plant communities, but areas with native character persist. The extensive shallow margins in the lake support a large vegetated area.

In 2007 the depth extent of plants was 1.5 to 2.5 m shallower than 2001, indicating a sustained reduction in the water clarity of the lake. Large amounts of unattached plants seen at this time also suggest a recent stressful period for plant survival. The LakeSPI score decreased only slightly between the two surveys, reflecting the compensating effect between decreased Native Condition Index and decreased Invasive Impact Index.

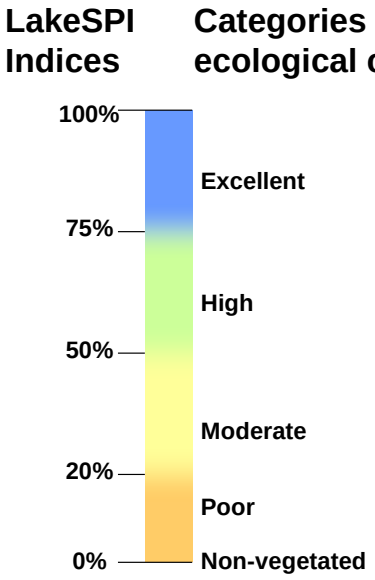
These changes in the scores signal a somewhat unstable lake system vulnerable to further deterioration. In particular, the possible interplay between variable water clarity and exposure to wind could deleteriously impact the vegetation and future water quality. However, the lake does have features known to stabilise and protect lake ecological integrity including extensive native plants and their seed banks, and large populations of filter-feeding mussels.

Table 58: LakeSPI results for Lake Taharoa.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	100	100	0
Historical data	1983	45	58	67
	2001	41	53	70
Present day	2007	39	46	63

5. Discussion

Lakes of the Waikato Region displayed a wide range of current LakeSPI scores from having no submerged vegetation (0%) to a maximum LakeSPI Index of 91%. For the purposes of ranking and discussing these results, lakes have been categorised into five main groups indicating overall lake condition based on the LakeSPI Index. Lakes are grouped as being in an 'excellent', 'high', 'moderate', 'poor', or 'non-vegetated' condition (Figure 10).



Note: These categories are imposed on a continuum scale of scores; therefore we recognise some flexibility in the placement of lakes with scores close to the transition between categories. Lake placement in these cases will be made using expert opinion based on the current status of the lake and the pressures exerted on it.

Figure 10: LakeSPI indices categorise lakes into five lake condition groups.

Table 59: Summary of current LakeSPI indices for lakes in the Waikato Region.

Key to lake types:

Peat	Riverine	Volcanic	Hydro	Dune

Lake	Lake Type	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)	Overall condition
Serpentine East		91	79	0	Excellent
Serpentine North		89	75	0	
Rotopounamu		71	43	0	
Mangakaware		63	65	33	High
Opouri		58	33	4.4	
Rotoroa (Hamilton)		52	50	37	
Harihari		45	59	65	
Kainui (D)		44	28	0	
Taharoa		39	46	63	
Taupo		36	47	78	
Ngahewa		29	26	67	
Parkinson		28	35	82	Moderate
Aratiatia		27	39	84	
Rotoiti		23	25	84	
Rotoaira		23	27	90	
Parangi		22	11	75	
Puketi		21	18	85	
Otamatearoa		18	29	96	
Ohakuri		14	10	96	
Arapuni		12	10	97	
Waipapa		12	9	96	Poor
Atiamuri		11	3	99	
Whakamaru		10	8	96	
Maraetai		9	3	97	
Karapiro		9	3	97	
Areare		0	0	0	Non vegetated
Hakanoa		0	0	0	
Hinemaiamai (B)		0	0	0	
Hotoananga		0	0	0	
Kaituna		0	0	0	
Kimihia		0	0	0	
Koromatua		0	0	0	
Mangahia		0	0	0	
Maratoto		0	0	0	

Lake	Lake Type	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)	Overall condition
Milicich		0	0	0	
Ngaroto		0	0	0	
Ohinewai		0	0	0	
Okowhao		0	0	0	
Pataka		0	0	0	
Posa		0	0	0	
Rotokauri		0	0	0	
Rotokawau		0	0	0	
Rotomanuka		0	0	0	
Rotongaro		0	0	0	
Rotongaroiti		0	0	0	
Ruatuna		0	0	0	
Serpentine South		0	0	0	
Tunawhakapeka (E)		0	0	0	
Tutaeinanga		0	0	0	
Waahi		0	0	0	
Waikare		0	0	0	
Whangape		0	0	0	

Each of the lakes in this study is also considered in relation to lake type, as this often indicates geographic grouping and common pressures or impacts on the lakes.

Peat Lakes

Peat lakes contained the largest group of lakes with 21 lakes surveyed for this report. Of these, 16 were classed as 'non-vegetated', one as 'moderate', two as 'high', and two were classed as 'excellent' (Table 59).

Lakes Serpentine North and Serpentine East still remain the most notable of all lakes in this group, retaining close to their original pristine condition and ranked in 'excellent' overall condition. One of the most remarkable features of Lakes Serpentine East and Serpentine North is the absence of any problematic invasive submerged weeds. This is likely to be a key factor in these lakes having avoided the fate of permanent vegetation collapse that typically follows a period of domination by weeds, such as *Egeria densa*, as observed in most other lakes. However, despite their high LakeSPI indices, these lakes show distinctive signs of stress. The impact of nutrient enrichment in the Serpentine Lakes is apparent with plants having seasonally high

abundance of epiphytic burdens attached to the plant surfaces, and variations in the depth development of vegetation in North Lake in particular. Additional disturbance pressure is exerted by herbivorous rudd and benthivorous catfish present in these lakes. A coarse fish removal programme was initiated by management agencies in 2001 (Neilson et al. 2004) and continues to the present (2009) with effort adapted to the initial catch rates as an indication of population size.

There were two lakes in this peat group categorised in the 'high' group (i.e., Mangakaware and Rotoroa). The current condition of Lake Rotoroa reflects the recent expansion of *Egeria densa*, which re-invaded in 2002 but was subsequently managed by a combination of herbicide treatment and handweeding of isolated colonies. Interestingly, Lake Rotoroa went through the same trends as the other Waikato lakes with invasive weed problems, coarse fish impacts and subsequent vegetation decline. For a period of ten years (1990-99) this lake remained in a de-vegetated state. In 1998, the lake showed significant vegetation recovery with re-appearance of charophytes in shallow water areas. These plants re-established in the lake from seeds (oospores) present in the lake sediments. The role of an abundant and viable 'seed bank' of native charophyte species is instrumental in vegetation recovery, but often the seed bank within lake sediments is buried and rendered non-viable by silt accumulation occurring during the dominance of invasive weed beds (de Winton and Clayton 1996). Seedling establishment is also susceptible to fish disturbance, where low levels of seed germination cannot result in plant establishment unless protected from fish. This has been demonstrated in Lake Rotoroa with the aid of fish exclusion cages (de Winton et al. 2002). The recent recovery of native vegetation within Lake Rotoroa may well have occurred due to regular herbicide control of nuisance weed beds during the 1970s and 1980s (Tanner et al. 1990b) when native plant seed banks would otherwise have been buried and rendered inactive.

The peat lake currently in a 'moderate' state, Lake Kainui (D) had no invasive species, but the plant cover was low and LakeSPI scores were based on less than five sites where native vegetation cover exceeded the 10% threshold. Slight fluctuations in future plant development would have a significant influence on these scores and therefore the results should be considered indicative only.

Sixteen of the twenty-seven lakes in the 'non-vegetated' category were peat lakes and were either devoid of submerged vegetation or covers did not exceed the 10% threshold for LakeSPI assessment. The most significant recent change recorded for any of the Waikato peat lakes is the loss of submerged vegetation in Serpentine South. Since the last survey in August 2008 and during the most recent survey in March 2009 submerged vegetation within the lake was found to have collapsed with only sparse

remnants of native vegetation still remaining at covers that did not exceed the 10% required to generate a LakeSPI score.

The most recent survey at Lake Serpentine South gave the first record of the introduced bladderwort *Utricularia gibba* for lakes of the Waikato Region, with a subsequent record at a nearby peat lake, Lake Milicich. This invasive plant has spread south from the Northland and Auckland Regions, where 32 lakes have been infested since 2004 alone (de Winton et al. 2009). It appears that *U. gibba* is actively spread by waterfowl from seed or possibly its fine, entangling growths. In Northland this species can form high covers of smothering growths over other plants and it performs best in smaller, sheltered eutrophic lakes that possess submerged vegetation. If *U. gibba* has a similar performance in the Waikato Region, we would expect impacts at lakes such as Serpentine East and North and a deteriorating condition of these water bodies in the future.

Riverine Lakes

The riverine lakes share common properties with the peat lakes in terms of depth, catchment influences and vulnerability to change. All of the Waikato riverine lakes are naturally shallow (<5m depth) and their higher wind fetch have led to increased internal sediment re-suspension and reduced water clarity, especially following collapse of submerged vegetation.

All nine of the riverine lakes surveyed were classed as "non-vegetated" being either devoid of submerged vegetation or having covers that did not exceed the 10% threshold for LakeSPI assessment. Lakes Waikare, Waahi and Whangape have the earliest records of vegetation condition that date back to 1869-71, when diverse and abundant native vegetation was recorded. These historical records are consistent with that expected from many of the Waikato lakes in an undisturbed or pristine condition and this information was used to help generate Pristine LakeSPI indices.

Connections with the Waikato River system or other lakes has meant that coarse fish such as koi carp have established and exert an ongoing disturbance that further reduces the chances of submerged plants recovering.

Volcanic Lakes

The larger size, depth and water volume of the six volcanic lakes provide a greater buffering capacity against land use effects, particularly water clarity, compared to small shallow lakes. While most of the volcanic lakes still possess extensive

submerged vegetation, the smaller lakes have undergone changes suggesting they are not in a stable state.

Two of the lakes were classed as 'high', with Lake Rotopounamu the highest ranked because of the absence of invasive species. The Native Condition Index for this lake was reduced by the recent loss of charophyte beds that previously dominated the submerged vegetation. This may be a temporary phenomenon, however, it is not known whether native charophyte seed banks would enable a rapid vegetation recovery. Lake Opouri is also currently classified as having a 'high' ecological condition due to the restricted presence of the relatively benign weed *Elodea canadensis*. However, this lake has shown signs of instability, with the most recent improved scores being influenced by reduced weed dominance even though there were also retractions in the depth extent of vegetation.

The larger of the volcanic lakes are more likely to retain remnants of their original vegetation, especially in the shallow and deep water zones. Wind-generated wave action in large lakes creates a shallow-water disturbance zone that is often dominated by a diverse assemblage of low-growing, turf-forming, native species, such as documented for Lake Rotoaira. The mid-depth zone is where invasive weed species have the greatest impact. In the past, native charophytes grew in deeper water beyond the displacing influence of invasive weed species in Lake Rotoaira. Today however, the recent establishment of *Ceratophyllum demersum* (hornwort) with its deeper growing beds is leading to widespread loss of native charophyte meadows in deeper water. The 'moderate' LakeSPI category for Lake Taupo, in particular, and Lake Rotoaira are attributable to the extensive impact that hornwort has had on submerged vegetation.

Ecological condition of Lake Ngahewa has recently improved from 'non-vegetated' to 'poor', whilst Lake Tutaeinanga decreased from 'high' to 'non-vegetated'(<10% plant cover). This signifies these small lakes are close to ecological limits for submerged plants and are vulnerable to becoming permanently de-vegetated.

Hydro lakes

The Waikato River hydro lakes share similar characteristics of high water flow-through, and artificial water level fluctuations, although the operating range varies substantially. The LakeSPI scores for the Waikato Hydro lake series differentiate Lake Aratiatia with 'moderate' condition from the other seven lakes of 'poor' condition. Lake Aratiatia's better condition is partially attributable to the high water quality of flows from Lake Taupo, a short residence time and a daily water level fluctuation that helps promote an amphibious turf on the lake margins that is tolerant of periodic

exposure and immersion (e.g., Riis and Hawes 2003). Lake Aratiatia also records *Isoetes kirkii*, which is still prominent in Lake Taupo but has become extinct in the lowland riverine lakes of the Waikato Region. Although invasive species dominate the submerged vegetation in Aratiatia, these plants are less problematic than those dominating downstream hydro lakes and their depth of colonisation is restricted more by water flow than by water clarity.

The remainder of the Waikato River hydro lakes have similar scores that are influenced largely by the almost complete domination of vegetation by *Ceratophyllum demersum*.

Dune Lakes

All of the dune lakes had a submerged vegetation, but were impacted to a significant degree by invasive plant species (Invasive Impact scores >60%). Six of the dune lakes had a 'moderate' ecological condition and Lake Otamateroa was in the 'poor' category. Lake Harihari was the highest ranked of the dune lakes, and only had the relatively benign weed *Elodea canadensis* recorded and retained significant deep-water charophyte beds beyond the main depth of impact from *E. canadensis*. Lake Taharoa has been colonised by *Lagarosiphon major* in addition to *E. canadensis*, and also shows signs of vegetation instability. Lake Parangi, surveyed for the first time in 2008 also recorded *E. canadensis* forming dense weed beds down the maximum depth of plant growth. A higher impact weed, *Egeria densa*, dominated most of Lakes Puketi, Rotoiti and Parkinson, whilst the greatest impact was seen from *Ceratophyllum demersum* in Lake Otamatearoa.

Historical descriptions from the 1950s (Cunningham et al. 1953) exist for several dune lakes such as Lake Otamatearoa and Thompsons Lake (Lake Whatihua located in Auckland Region, but adjacent to Lakes Puketi and Rotoiti). These descriptions provide the earliest information on the native, charophyte dominated vegetation in Waikato dune lakes, however only remnants of native vegetation remain, with Lake Harihari presently the best remaining example. The earliest historical records for the other Waikato dune lakes were gathered from the 1970s or 1980s onwards.

National comparison

The Waikato Region has a high proportion of non-vegetated lakes compared to other regions or nationally (Fig. 11). In most situations this represents the ultimate degraded state of a lake, where water quality conditions have deteriorated to the point where the growth of submerged plants can no longer be supported. Water quality impacts are in

turn a consequence of the history of catchment modification and intensive agriculture in the region.

A smaller proportion of Waikato lakes fall into the 'poor' category, representing extensive invasion and dominance by one of the country's worst weeds, *Ceratophyllum demsersum*. Similar groups of substantially invaded lakes are represented in Auckland, Bay of Plenty and the Hawkes Bay Regions in particular.

A 'moderate' condition group of lakes containing most of the volcanic and dune lakes in the Waikato Region is impacted to varying degrees by invasive weeds. The largest proportion of lakes nationally fall into this 'moderate' category.

The Waikato Region has the smallest combined proportion of lakes in the 'high' to 'excellent' category compared to other regions or nationally. The small Waikato lakes in the excellent group remain close to the maximum ecological condition expected for their type.

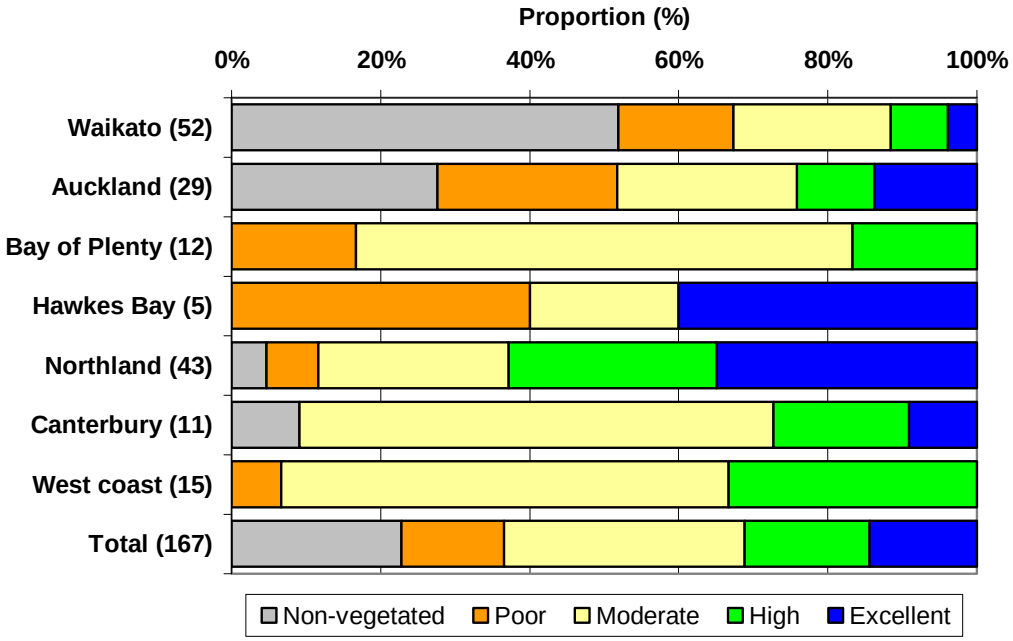


Figure 11: Proportions of lakes that fall into five categories of LakeSPI Index, showing total and regional differences, with number of lakes shown in parenthesis.

This national comparison does not take into account the different types of lakes in each region, for example, the high representation in the Waikato Region of hydro lakes and small, sensitive peat lakes. Nevertheless, it suggests a generally poorer condition of the Waikato Region lakes, with those few that remain in a 'high' to 'excellent' condition vulnerable to future degradation.

LakeSPI indices on the Waikato lakes have provided valuable inter-lake comparisons and information on historical changes. Continued long-term monitoring is recommended for identifying future changes in the condition of these lakes. For lake managers, LakeSPI provides relevant information for regional and national reporting requirements, including operational monitoring and state of the environment reporting. Over time the results can be used to assess the effectiveness of catchment and lake management initiatives.

6. Recommendations

1. A schedule of LakeSPI surveys should be developed in association with Environment Waikato staff, with priorities and timing of re-survey based on perceived lake value, stability and known threats to the lakes. Additional lakes should be added where there are perceived knowledge gaps. This schedule should specifically address:

    - **Lake Taupo**. The selection of baseline sites in Lake Taupo, following LakeSPI protocols, has not yet been done. It is recommended that sites are chosen with reference to historical data and general knowledge about vegetation development with this waterbody and the lake surveyed to provide an accurate present day assessment and indications of trends to date.

    - **Lake Rotopounamu**. Resurvey in late summer 2010 to assess charophyte recovery and the potential for seed bank reactivation in the absence of natural recovery. If native vegetation has recovered it is recommended that a LakeSPI assessment be carried out to reflect its natural condition.

    - **Restoration initiatives**. Baseline and re-surveys be incorporated into restorative or management initiatives (e.g., catchment mitigation, weed control measures) to monitor ecological improvements.

    - **Knowledge gaps**. Lakes that have not yet been investigated and where vegetation resources are likely to be present (e.g., additional dune, volcanic, artificial and kast lakes) should be prioritised. However inclusion of select non-vegetated lakes with the potential for recovery should not be excluded (e.g., Lake Hotoananga, Serpentine South).

2. LakeSPI information within this report should be assimilated into Environment Waikato's system for identifying candidate lakes for potential protection or restoration (e.g., Reeves et al. 2008, Methods for ranking of lake ecosystems for biodiversity management in the Waikato Region).

7. Acknowledgments

Aleki Taumoepeau and Rohan Wells (NIWA) undertook survey diving. EW kindly supplied the maps contained within this report. We would also like to thank land owners for access permission to the lakes. Photos for Lakes Areare, Hotananga, Milicich, Pataka and Posa were supplied by Keri Neilson (EW), and for Lake Opouri by David Perry (EW). Ongoing development and refinement of the LakeSPI method is supported by funding from the Foundation for Research Science & Technology (contract C01X0501).

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8. Appendix 1: List of plant species encountered for each lake group, based on the most recent visit and including those marginal and emergent species on the lake edge. † = exotic species.

Table 1: Peat Lakes (Continued in following tables)

Lake	Serpentine East	Serpentine North	Rotoroa (Hamilton)	Mangakaware	Kainui (D)	Areare	Hotoananga	Kaituna	Koromatua	Mangahia
Survey date	**10/03/2009**	**10/03/2009**	**8/05/2009**	**25/05/2005**	**24/05/2005**	**14/11/1991**	**2001**	**1/02/2007**	**1/02/2007**	**1/02/2007**
Submerged species							None			
Chara australis		*	*	*						
†Egeria densa			*	*						
†Elodea canadensis				*						
Glossostigma submersum				*						
Myriophyllum propinquum				*		*				
Nitella aff. cristata	*	*	*	*	*	*				
Nitella pseudoflabellata			*							
Potamogeton cheesemannii	*	*	*							
†Potamogeton crispus										
Potamogeton ochreatus	*		*	*						
†Utricularia gibba										
Marginal/emergent species										
†Azolla pinnata						*			*	
Baumea articulata			*					*		
Baumea sp.					*					
Baumea teretifolia										
Bolboschoenus fluviatilis				*						
†Callitriche stagnalis										

Lake	Serpentine East	Serpentine North	Rotoroa (Hamilton)	Mangakaware	Kainui (D)	Areare	Hotoananga	Kaituna	Koromatua	Mangahia
Survey date	**10/03/2009**	**10/03/2009**	**8/05/2009**	**25/05/2005**	**24/05/2005**	**14/11/1991**	**2001**	**1/02/2007**	**1/02/2007**	**1/02/2007**
Carex secta								*	*	*
Eleocharis sphacelata	*	*	*		*	*				*
†Galium palustre									*	
†Glyceria maxima								*		
†Iris pseudacorus				*						
†Landoltia punctata										
Lemna minor				*					*	
Ludwigia palustris				*						
†Ludwigia peploides				*				*	*	
†Lycopus europaeus								*	*	
†Myriophyllum aquaticum										
†Nymphaea sp.			*							
†Paspalum distichum					*			*	*	*
†Polygonum sp.										*
Typha orientalis				*		*		*	*	

Lake	Maratoto	Milicich	Ngaroto	Pataka	Posa	Rotokauri	Rotokawau	Rotomanuka	Ruatuna	Serpentine South	Tunawhakapeka (E)
Survey date	**11/03/2009**	**9/03/2009**	**3/03/1992**	**21/06/2007**	**21/06/2007**	**Warr 1998**	**18/06/2007**	**21/06/2007**	**21/06/2007**	**10/03/2009**	**18/06/2007**
Submerged species						None					
Chara australis											
†Egeria densa											
†Elodea canadensis											
Glossostigma submersum											
Myriophyllum propinquum											
Nitella aff. cristata				*				*		*	
Nitella pseudoflabellata											
Potamogeton cheesemannii											
†Potamogeton crispus											*
Potamogeton ochreatus										*	
†Utricularia gibba		*								*	
Marginal/emergent species											
†Azolla pinnata											
Baumea articulata											
Baumea sp.											
Baumea teretifolia					*						
Bolboschoenus fluviatilis											
†Callitriche stagnalis											*
Carex secta											
Eleocharis sphacelata	*	*					*	*	*	*	

Lake	Maratoto	Milicich	Ngaroto	Pataka	Posa	Rotokauri	Rotokawau	Rotomanuka	Ruatuna	Serpentine South	Tunawhakapeka (E)
Survey date	**11/03/2009**	**9/03/2009**	**3/03/1992**	**21/06/2007**	**21/06/2007**	**Warr 1998**	**18/06/2007**	**21/06/2007**	**21/06/2007**	**10/03/2009**	**18/06/2007**
†Galium palustre											
†Glyceria maxima											
†Iris pseudacorus											
†Landoltia punctata				*							
Lemna minor											
Ludwigia palustris			*								
†Ludwigia peploides			*							*	
†Lycopus europaeus			*								
†Myriophyllum aquaticum							*				
†Nymphaea sp.											
†Paspalum distichum		*	*	*	*						
†Polygonum sp.											
Typha orientalis			*	*	*			*	*		

Table 2: Riverine Lakes

Lake	Hakanoa	Kimihia	Ohinewai	Okowhao	Rotongaro	Rotongaroiti	Waahi	Waikare	Whangape
Survey date	**13/11/1991**	**13/09/1991**	**3/03/2008**	**9/03/2009**	**24/05/2005**	**25/05/2005**	**28/10/2005**	**3/03/2008**	**15/02/2005**
Submerged species									
†Ceratophyllum demersum							*		
Elatine gratioloides						*			
Glossostigma elatinoides						*			
Glossostigma submersum		*							
†Lagarosiphon major							*		
Lilaeopsis ruthiana						*			
Myriophyllum propinquum						*			
Myriophyllum triphyllum							*		
Nitella aff. cristata	*								
Marginal/emergent species									
†Alternanthera philoxeroides									*
†Azolla pinnata	*	*							
Baumea articulata		*					*		
Bolboschoenus fluviatilis									*
Eleocharis sphacelata	*	*					*		
†Juncus effusus									*
†Ludwigia palustris		*			*	*	*		*
†Ludwigia peploides	*	*		*					
†Lycopus europaeus	*						*		
†Myriophyllum aquaticum	*	*					*		*
†Paspalum distichum		*		*					

Lake	Hakanoa	Kimihia	Ohinewai	Okowhao	Rotongaro	Rotongaroiti	Waahi	Waikare	Whangape
Survey date	**13/11/1991**	**13/09/1991**	**3/03/2008**	**9/03/2009**	**24/05/2005**	**25/05/2005**	**28/10/2005**	**3/03/2008**	**15/02/2005**
Persicaria decipiens		*							
†Polygonum sp.									*
Schoenoplectus tabernaemontani	*								
Typha orientalis	*	*					*		

Table 3: Hydro lakes.

Lake	Aratiatia	Ohakuri	Arapuni	Waipapa	Atiamuri	Whakamaru	Maraetai	Karapiro	Hinemaimaia B
Survey date	**2/03/2009**	**3/03/2009**	**4/03/2009**	**17/03/2009**	**3/03/2009**	**4/03/2009**	**16/03/2009**	**4/03/2006**	**19/11/2004**
Submerged species									
†Ceratophyllum demersum	*	*	*	*	*	*		*	
Chara australis	*		*						
Chara fibrosa	*								
Chara globularis	*								
Crassula sinclairii			*						
†Egeria densa	*	*	*	*	*	*		*	
Elatine gratioloides	*		*	*		*			
Eleocharis pusilla	*								
†Elodea canadensis	*	*	*		*				
Glossostigma elatinoides	*		*	*	*				
Glossostigma submersum	*		*	*	*	*		*	*
Isoetes kirkii	*								
†Lagarosiphon major	*	*			*	*			
Lilaeopsis ruthiana	*	*	*	*	*	*			
Myriophyllum pedunculatum	*								
Myriophyllum propinquum	*	*	*		*	*			*
Myriophyllum triphyllum	*								
Myriophyllum votschii					*				
Nitella aff. cristata	*			*				*	*
Nitella hyalina	*								

Lake	Aratiatia	Ohakuri	Arapuni	Waipapa	Atiamuri	Whakamaru	Maraetai	Karapiro	Hinemaimaia B
Survey date	**2/03/2009**	**3/03/2009**	**4/03/2009**	**17/03/2009**	**3/03/2009**	**4/03/2009**	**16/03/2009**	**4/03/2006**	**19/11/2004**
Nitella leonhardii	*								
Nitella pseudoflabellata	*								
Pilularia novae-zelandiae	*								
Potamogeton cheesemannii	*		*						
†Potamogeton crispus	*	*							
Potamogeton ochreatus	*	*							*
Ranunculus limosella	*		*						
†Ranunculus trichophyllus	*								
Ruppia polycarpa	*								
Marginal/emergent species									
†Glyceria maxima		*						*	
†Juncus articulatus		*				*			
†Ludwigia palustris						*			
†Ludwigia peploides						*			
†Nymphaea mexicana		*							
†Nymphaea sp.				*					
Persicaria decipiens				*			*		
Pratia angulata		*				*			
Schoenoplectus tabernaemontani		*		*		*		*	
Typha orientalis		*		*		*			*

Table 5: Volcanic lakes.

Lake	Rotopounamu	Opouri	Taupo	Ngahewa	Rotoaira	Tutaeinanga
Survey date	**19/11/2004**	**18/11/2004**	**26/03/2003**	**4/03/2008**	**26/03/2007**	**4/03/2008**
Submerged species						
Callitriche petriei					*	
†Ceratophyllum demersum			*		*	
Chara australis		*	*	*		
Chara globularis			*		*	
†Egeria densa						*
Elatine gratioloides		*				
Eleocharis pusilla					*	
†Elodea canadensis		*	*	*	*	
Glossostigma cleistanthum					*	
Glossostigma elatinoides		*			*	
Glossostigma submersum		*	*			
Isoetes kirkii			*		*	
†Lagarosiphon major			*	*	*	
Lilaeopsis ruthiana	*		*		*	
Myriophyllum pedunculatum	*					
Myriophyllum propinquum		*	*		*	
Myriophyllum triphyllum			*		*	
Nitella aff. cristata			*		*	
Nitella leonhardii			*		*	
Nitella pseudoflabellata			*		*	

Lake	Rotopounamu	Opouri	Taupo	Ngahewa	Rotoaira	Tutaeinanga
Survey date	**19/11/2004**	**18/11/2004**	**26/03/2003**	**4/03/2008**	**26/03/2007**	**4/03/2008**
Nitella opaca			*			
Nitella stuartii					*	
Pilularia novae-hollandiae						
Potamogeton cheesemannii			*		*	
†Potamogeton crispus			*		*	
Potamogeton ochreatus		*	*	*	*	*
Lobella perpusilla					*	
Ranunculus glabrifolius					*	
†Ranunculus trichophyllus			*		*	
Ranunculus limosella			*			
Ruppia polycarpa			*		*	
Stuckenia pectinata					*	
Triglochin striata					*	
Zannichellia palustris					*	
Marginal/emergent species						
Baumea arthrophylla	*					
Eleocharis acuta		*				
Eleocharis sphacelata		*		*		*
Hydrocotyle novae-zeelandiae	*					
†Juncus articulatus	*				*	
†Juncus bulbosus	*					
†Ranunculus flammula	*					
Typha orientalis		*		*		

Table 6: Dune lakes.

Lake	Parangi	Otamatearoa	Harihari	Parkinson	Rotoiti	Puketi	Taharoa
Survy date	**20/03/2008**	**9/03/2009**	**23/03/2009**	**18/10/2004**	**18/10/2004**	**18/10/2004**	**17/04/2007**
Submerged species							
†*Ceratophyllum demersum*		*					
Chara australis		*	*			*	*
Chara fibrosa		*	*				
Chara globularis		*	*				
†*Egeria densa*				*	*	*	
†*Elodea canadensis*	*	*	*				*
Glossostigma elatinoides						*	
Glossostigma submersum						*	
†*Lagarosiphon major*							*
Lilaeopsis novaezelandiae						*	
Limosella lineata						*	
Myriophyllum pedunculatum						*	
Myriophyllum propinquum		*		*	*	*	
Myriophyllum triphyllum	*	*	*	*			*
Nitella aff. Cristata		*		*		*	*
Nitella hyalina		*	*				
Nitella pseudoflabellata		*	*		*	*	
Potamogeton cheesemannii		*	*	*	*	*	
†*Potamogeton crispus*		*					*
Potamogeton ochreatus	*		*				*

Lake	Parangi	Otamatearoa	Harihari	Parkinson	Rotoiti	Puketi	Taharoa
Survy date	**20/03/2008**	**9/03/2009**	**23/03/2009**	**18/10/2004**	**18/10/2004**	**18/10/2004**	**17/04/2007**
Marginal/emergent species							
†Azolla pinnata		*		*	*	*	
Baumea articulata		*	*		*	*	
Carex secta		*					
Eleocharis acuta		*		*	*	*	
Eleocharis sphacelata		*	*	*	*	*	*
†Juncus articulatus					*		
Lemna minor				*	*	*	
†Ludwigia palustris		*		*	*	*	
Myriophyllum robustum		*					
†Nymphaeae sp.		*					
†Paspalum distichum		*				*	
Ranunculus glabrifolius					*		
Ranunculus macropus		*					
Schoenoplectus tabernaemontani			*				
Typha orientalis	*	*	*			*	*