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Assessment of the ecological condition of lakes in the Waikato region using LakeSPI – 2010

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Prepared by:
Tracey Edwards, Mary de Winton, John Clayton
National Institute of Water and Atmospheric Research (NIWA)

For:
Environment Waikato
PO Box 4010
HAMILTON EAST

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National Institute of Water & Atmospheric Research Ltd
Gate 10, Silverdale Road, Hamilton
P O Box 11115, Hamilton, New Zealand
Phone +64-7-856 7026, Fax +64-7-856 0151
www.niwa.co.nz

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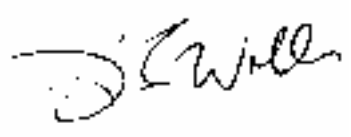

Rohan Wells

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Paul Champion

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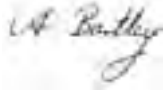


Executive Summary

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).

All lakes of the Waikato Region have shown a significant reduction in LakeSPI scores from the pre 1900 'pristine' state. Lakes displayed a wide range of current LakeSPI scores from having no submerged vegetation (0%) to a maximum LakeSPI Index of 89%. From the lakes assessed for this report, one lake was classified in 'excellent' condition (LakeSPI Index $\geq$ 75%); four lakes in 'high' condition, eleven in 'moderate' condition, seven in 'poor' condition and the remaining twenty-nine 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.

Lake Serpentine North, was the only lake to have retained close to its original pristine condition and was ranked in "excellent" overall condition. Despite the high LakeSPI score, it remains under threat from invasion by exotic weeds and the status of this lake will fall in the event that the alien bladderwort *Utricularia gibba* establishes. This is now likely as this weed is widely spread by waterfowl and is present in the adjacent Lakes Serpentine South and East. Vegetation in Serpentine North also shows advanced signs of stress, consistent with the type of changes that have taken place in most other Waikato 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 (Serpentine East and Rotoroa). Lake Rotopounamu was the highest ranked lake in this group because of the absence of any invasive species. However, a recent loss of the charophyte beds that previously dominated the submerged vegetation has resulted in lower LakeSPI scores than would otherwise be expected for this lake. A resurvey is recommended to assess charophyte recovery, as a positive change in charophyte covers could see this lake return to 'excellent' condition in the future. Lake Serpentine East recently dropped from an 'excellent' to 'high' category due to invasion by the alien bladderwort *Utricularia gibba*, and reduced native plant diversity.

Eleven lakes were ranked in 'moderate' condition and although all of these lakes still supported native plant communities, all 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 were present beyond the range occupied by *E. canadensis*. Inclusion of the dune lake Lake Otamatearoa in this category reflects recent weed control initiatives, but this status will not be retained if the invasive weed *Ceratophyllum demersum* is allowed to recover its former abundance. All seven dune lakes surveyed for this report were ranked in this 'moderate' category, which also included three volcanic lakes and the uppermost hydro-lake in the Waikato River chain that is immediately downstream from Lake Taupo.

The remaining seven hydro-lakes in the Waikato River chain were ranked as being in 'poor' condition. All had similar LakeSPI scores that are influenced by the almost complete domination of vegetation by *C. demersum*, New Zealand's worst submerged weed species. It is however noted that maintaining invasive species in a lake is preferable to macrophyte collapse and algal dominance.

The remaining twenty-nine lakes assessed in this report were categorised as being 'non-vegetated', either devoid of submerged vegetation or having submerged vegetation 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 eighteen of the twenty-seven peat lakes assessed in this report. Recently vegetation in several peat lakes (Lakes Serpentine South, Mangakaware, and Kainui) has fallen below the plant abundance (10% cover) where a LakeSPI score is generated and lakes are now termed 'non-vegetated'. These lakes may be at the threshold between a vegetated and non-vegetated state and would be sensitive to future management initiatives.

LakeSPI enables the condition of different types of lakes to be compared, for example, small shallow water bodies with larger deeper lakes. The Waikato Region, compared with lakes nationally, have a higher proportion of non-vegetated lakes indicating a high level of degradation from catchment activities such as 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, *C. demersum*. Nationally, most lakes fall into the 'moderate category, which in the Waikato Region contains most of the volcanic and dune lakes that are impacted to varying degrees by invasive weeds.

LakeSPI indices for the 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 LakeSPI 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), 2008 (Edwards et al. 2008) and 2009 (Edwards et al. 2009). This current report updates assessments on six of the fifty-two lakes currently assessed using LakeSPI.

The study brief also requires all lakes to be grouped into categories based upon their current day condition. These LakeSPI groupings are: 'excellent', 'high', 'moderate', 'poor' or 'non-vegetated'; and support the Ministry for the Environment initiative to ensure national consistency in terminology and reporting.

1.2 Study lakes

Fifty-two Waikato lakes in total have been assessed using LakeSPI. The location of lakes is indicated in Figure 1 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 they were known to be de-vegetated and recent recovery was unlikely (five lakes), The remaining 47 lakes were surveyed from late 2004 to 2010 (Table 1).

Figure 1: 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 maximum 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	22/04/2010
Kainui (D)		0.32	6.7	22/04/2010
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	22/04/2010
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	08/03/2010
Parangi		0.12	17.6	20/03/2008
Parkinson		0.019	8	20/04/2010
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	09/04/2010
Serpentine North		0.053	4	09/04/2010
Serpentine South		0.083	3.6	09/04/2010
Taharoa		2.05	9.2	21/04/2010
Taupo		622.63	162.8	-
Tunawhakapeka (E)		0.08	1	18/06/2007
Tutaeinanga		0.031	11	04/03/2008
Waahi		5.37	5	20/04/2010
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.

1.3 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 Taupo volcanic zone lakes.

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 (1870) 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., Lakes Waikare and 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 1800's 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.

1.4 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 2). Today, Lake Serpentine North and Lake Rotopounamu are the only known remaining examples of Waikato lakes that remain in an all-native vegetated state.

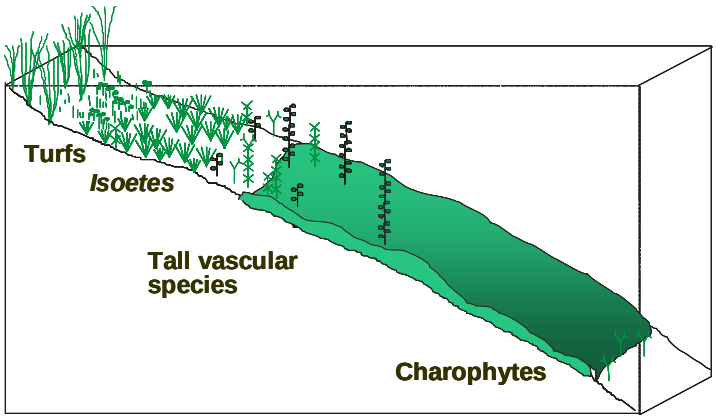


Figure 2: Depth profile illustrating the main components of native lake vegetation.

With the introduction of invasive submerged plant species over the past 150 years, native plants in most lakes were displaced by invasive weed species, which often formed tall mono-specific weed beds (Figure 3). Some west coast dune lakes (Lake Taharoa, Puketi, Rotoroa and Parkinson) remain in this state and are vulnerable to vegetation collapse. Many of the Waikato lakes have now proceeded to the next and, often final stage where de-vegetation has occurred (Figure 4). 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).

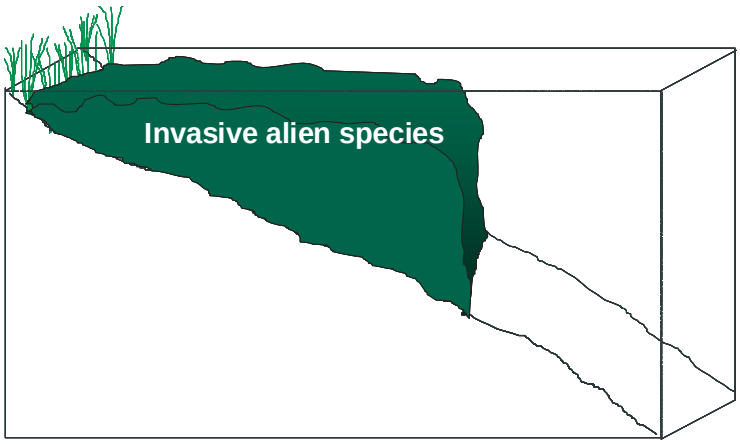


Figure 3: Depth profile illustrating the potential impact of invasive species.

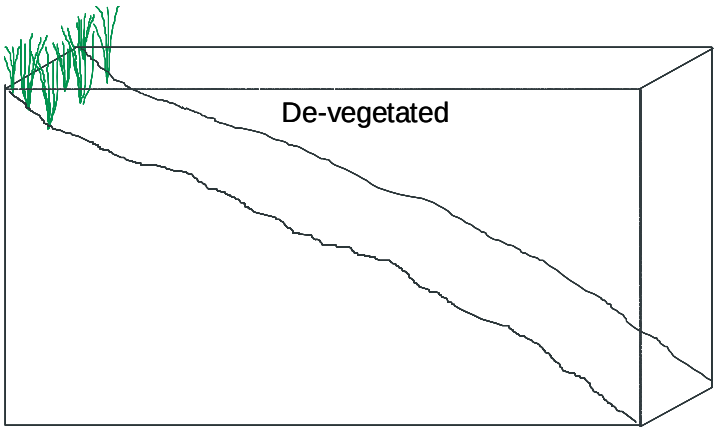


Figure 4: Depth profile illustrating a de-vegetated lake.

2. Study methods

2.1 LakeSPI

LakeSPI takes advantage of the usefulness of submerged plants as indicators (Clayton and Edwards 2006b). This includes their ease of observation, ability to integrate conditions over time, and sensitivity to catchment based impacts in the littoral zone. LakeSPI also provides a direct measure of the impact by alien invasive weeds.

Key assumptions of the LakeSPI method are that native plant species and high plant diversity 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 2006b).

Features of aquatic vegetation 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 of vegetation.

- '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, which is often undesirable.

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

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 potential score. Scoring potential reflects the maximum depth of the lake. This normalises the results from often very different types of lakes and allows their comparison. 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%.

2.2 Lake surveys

For this report update, the submerged vegetation in Lakes Hotoananga, Kainui, Mangakaware, Otamatearoa, Parkinson, Taharoa, Waahi and Serpentine lakes was assessed in March or April 2010 using the LakeSPI survey method (Clayton and

Edwards 2006b). At each selected baseline site, scuba divers swam from the lake shore to the deepest extent of the vegetation. Depth extent (±0.1 m using a dive computer) was defined as the cut-off for 10% plant cover, with ≥75% cover defining charophyte 'meadows'. The presence and depth extent of key native plant communities were noted, and their combined proportional contribution to the vegetation was estimated. The presence of any of 10 invasive weeds was also noted, together with their depth extent, the nature of weed cover, height, and overall proportional contribution to the vegetation.

For full LakeSPI method details, the LakeSPI Technical Report and User Manual can be viewed at http://www.niwascience.co.nz/ncwr/tools/lakespi. An online LakeSPI web reporting system (www.lakespi.niwa.co.nz) enables ready access to results in a form suitable for lake monitoring purposes and trend reporting.

2.3 Baselines

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

1. Pristine condition

This baseline usually describes the best possible lake condition, which in most New Zealand lakes would be what it theoretically was in pre-impacted times. However, because suitable pre-impact submerged vegetation records are not available for most lakes, we have adopted the limitation posed by lake depth as the maximum scoring potential for all lakes for the purpose of establishing a pristine baseline. 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. As peat influence on these lakes diminished through drainage of surrounding peat bogs, then water clarity and pH are likely to have increased to a level where submerged vegetation could develop. 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 potentially 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.

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. Prior application of the LakeSPI method for monitoring also provides a time trend against which to gauge recent changes.

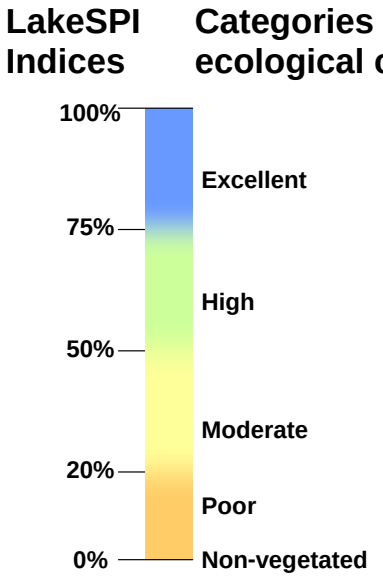
3. Present day condition

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.

2.4 Lake classification

For the purposes of ranking and discussing results, lakes have been categorised into five main groups based on the LakeSPI Index. Lakes are grouped as being in an 'excellent', 'high', 'moderate', 'poor', or 'non-vegetated' condition (Figure 5). These new lake groupings support an MfE initiative to ensure national consistency in

terminology and reporting and allow for better comparisons of lakes nationally and regionally.



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 5: LakeSPI indices categorise lakes into five lake condition groups.

2.5 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 (1870) 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. Results

Lakes have been presented in sections based on lake type (Peat, Riverine, Volcanic, Hydro and Dune) and individual lake summaries in each section are listed in alphabetical order.

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 with indices presented as a percentage of each lakes maximum scoring potential.

3.1 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 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 three 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 bold 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 North	89	75	0
Serpentine East	62	71	37
Rotoroa (Hamilton)	52	50	37
Areare	0	0	0
Hotoananga	0	0	0
Kainui (D)	0	0	0
Kaituna	0	0	0
Koromatua	0	0	0
Mangahia	0	0	0
Mangakaware	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

3.1.1 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

3.1.2 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. Most recently, in 2010, a cyanobacteria algal bloom was noted on the eastern shore and the water was noticeably turbid. The charophyte *Nitella* aff. *cristata* formed low covers (<25%) to a depth of 1 m amongst the reeds beds of *Eleocharis sphacelata*, and *Potamogeton ochreatus* was also seen. However, because submerged vegetation was not present at the majority of sites investigated, this lake scored default LakeSPI values of 0%.

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
	2001	0	0	0
Present day	2010	0	0	0

3.1.3 Lake Kainui (D)

Lake condition:	Non-vegetated
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 2005 assessment found charophytes (*Nitella* aff. *cristata*) at covers exceeding 10% at three of the five sites investigated, and therefore the lake generated a moderate LakeSPI score (Table 5). It was noted however, that slight fluctuations in plant development would have a significant influence on future scores and results for such a lake should be considered indicative only.

In 2010 no submerged plants were found. It may be that periods of reduced humic colour inputs, from drainage, subsidence and carbon loss in the adjacent Kainui peat bog, allow temporary development of plants. This means that limited plant presence or absence does not indicate significant change in lake condition and scores for this lake should be interpreted with care.

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
	2005	44	28	0
Present day	2010	0	0	0

3.1.4 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

3.1.5 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

3.1.6 Lake Mangakaware

Lake condition:	Non-vegetated
Stability:	Declining
Lake type:	Peat
Maximum depth:	4.8 m

During the most recent visit in 2010, submerged plants exceeded 10% cover at fewer than half of the surveyed sites, generating a default LakeSPI Index of 0% (Table 8). *Nitella* aff. *cristata* and *Potamogeton ochreatus* grew within a narrow zone down to 1 m depth, and *Egeria densa* was also recorded. Earlier, in 2005, sparse vegetation comprising six species was described over wider depths of up to 1.8 m. The presence of the invasive weed *Egeria densa* has now been confirmed within the lake for in excess of nineteen years, but has not had a high invasive impact (Table 8), while the more benign weed *Elodea canadensis* was recorded for the first time in 2005.

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
	2005	63	65	33
Present day	2010	0	0	0

3.1.7 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

3.1.8 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	1991	0	0	0
Present day	2009	0	0	0

3.1.9 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 region's 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

3.1.10 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

3.1.11 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

3.1.12 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

3.1.13 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
	1977	34	33	67
	1979	20	20	85
Historical data	1989	23	27	85
	1990	11	0	93
	1991	17	7	88
Present day	2003*	0	0	0

* Anticipated score

3.1.14 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

3.1.15 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	11	0	91
	1991	18	7	87
	2001	0	0	0
Present day	2007	0	0	0

3.1.16 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
	1981	30	40	74
	1984	35	40	74
	1986	38	40	74
	1989	35	40	67
	1990	0	0	0
Historical data	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

3.1.17 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
	1991	0	0	0
Present day	2007	0	0	0

3.1.18 Lake Serpentine East (Rotopiko East)

Lake condition:	High
Stability:	Declining
Lake type:	Peat
Maximum depth:	4.4 m

With the introduction and rapid establishment of the alien bladderwort, *Utricularia gibba*, Lake Serpentine East has decreased from its previous position as the top ranking lake in the Waikato Region. Although charophyte meadows remain well developed, the abundance of native pondweeds (*Potamogeton* spp.) has decreased.

Previously, with a LakeSPI Index of 89-91% (close to its maximum potential), Lake Serpentine East was one of the only remaining Waikato lakes to have retained a well developed, solely native vegetation dominated by pondweeds (*Potamogeton* spp.) and charophytes. The recent invasion by *Utricularia gibba* (first noted February 2010) still poses an unknown threat to the native character of this lake and also to Serpentine North.

Table 20: LakeSPI results for Lake Serpentine East.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	97	93	0
	1977	89	73	0
	1991 - Nov‡	0	0	0
	2001 - July	91	80	0
	2002 - Feb	90	77	0
Historical data	2003 - March	89	75	0
	2005 – Sept	90	76	0
	2006 - March	91	79	0
	2007 - April	91	80	0
	2008 - March	91	78	0
	2009 - March	91	79	0
Present day	2010 - April	62	71	37

‡ Only two sites having a plant cover exceeding 10%.

3.1.19 Lake Serpentine North (Rotopiko North)

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

With a LakeSPI Index of 89% Lake Serpentine North currently represents the highest scoring water body in the Waikato Region, as it remains un-impacted by invasive plant species. Although the LakeSPI indices show excellent lake condition, the submerged vegetation is under stress (e.g., epiphytic burden, fish grazing, and 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. Spread by waterfowl, this alien bladderwort is likely to be introduced to many lakes in the Waikato Region over time.

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 - Nov	85	69	0
	2001 - Feb	93	84	0
	2003 - March	90	76	0
	2005 - Sept	90	77	0
	2006 - March	89	73	0
	2007 - April	93	83	0
	2008 - March	90	76	0
	2009 - March	89	75	0
Present day	2010 - April	89	75	0

3.1.20 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 and 2010 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 (from March 2009) 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	0	0	0
	2005‡	70	56	0
	2007	86	68	0
	2008	86	68	0
	2009	0	0	0
Present day	2010	0	0	0

‡ Lower scores based on average of five sites with only four sites having a plant cover exceeding 10%.

3.1.21 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

3.2 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 bold 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

3.2.1 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

3.2.2 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

3.2.3 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	14	0	89
	1991	0	0	0
Present day	2008	0	0	0

3.2.4 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

3.2.5 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

3.2.6 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	76	76	21
	1991[ϕ]	0	0	0
Present day	2005	0	0	0

[ϕ] Sparse vegetation (cover <10%)

3.2.7 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 (1870). Kirk's 1870 description for this lake noted "more copious vegetation" than Lakes Whangape and Waikare. By the late 1930s and 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. Most recently, in 2010 submerged plants were restricted to sparse (≤5% cover) milfoil fringes at the extreme shore edge (<0.3 m depth), while offshore stands of the reed *Eleocharis sphacelata* were also greatly reduced in extent.

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
	2005	0	0	0
Present day	2010	0	0	0

3.2.8 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	97	93	0
Historical data	1871	97	93	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

3.2.9 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
	1869	100	100	0
	1958	26	29	81
Historical data	1982	24	21	81
	1991	15	7	85
	2001	4	0	64
Present day	2005	0	0	0

3.3 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. Five of the volcanic lakes contain a mixed assemblage of native and invasive aquatic plant species, and one had low plant covers that did not exceed the threshold required for LakeSPI assessment.

Figure 7: Location of Taupo volcanic zone lakes within the Waikato Region with assessed lakes shown in bold 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

3.3.1 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	95	90	0
Historical data	1973	78	57	0
	1982	27	24	74
	1989	15	5	81
	2004	0	0	0
Present day	2008	29	26	67

3.3.2 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	96	93	0
Historical data	1984	34	30	54
	1989	30	23	62
Present day	2004	58	33	4

3.3.3 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
	1979	51	68	67
Historical data	1999	32	46	83
	2002	27	39	86
Present day	2007	23	27	90

3.3.4 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

3.3.5 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
	1977	54	67	59
Historical data*	1991	54	67	59
	2002	36	47	78

*All results for Taupo are indicative only

3.3.6 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	1982	36	29	52
	2004	52	35	23
Present day	2008	0	0	0

3.4 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 Condition 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

3.4.1 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

3.4.2 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 *Lagarosiphon major*, *Egeria densa* and *Ceratophyllum demersum* respectively, 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

3.4.3 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

3.4.4 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

3.4.5 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

3.4.6 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
	1982	12	10	93
Historic	2001	12	10	96
	2008	8	1	99
Present day	2009	9	3	97

3.4.7 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

3.4.8 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

3.4.9 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

3.5 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	35	49	77
Parkinson	23	29	82
Rotoiti	23	25	84
Parangi	22	11	75
Puketi	21	18	85
Otamatearoa	31	56	81

3.5.1 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

3.5.2 Lake Otamatearoa

Lake condition:	Moderate
Stability:	Improving
Lake type:	Dune
Maximum depth:	5 m

Recently, an attempt to eradicate the dominant weed, *Ceratophyllum demersum*, using the herbicide endothall has resulted in a partial recovery of resistant charophytes and led to an improved present day LakeSPI Index. Previously (2004-2009) the low LakeSPI score reflected the large impact of *C. demersum*, which was introduced some time after 1996. The invasive species *Elodea canadensis*, has also been present since at least 1950 (Cunningham et al. 1953). Without follow-up herbicide treatment, either for control or eradication, the LakeSPI status of this lake is likely to return to 2009 levels.

During the 2010 survey, the presence of the threatened plants *Myriophyllum robustum*, and *Utricularia australis* were re-confirmed growing 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
	1986	39	43	67
	2004	23	43	90
	2009	18	29	96
Present day	2010	31	56	81

3.5.3 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

3.5.4 Lake Parkinson

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

The invasive weed *Egeria densa* continues to dominate the vegetation, with previously recorded charophyte (*Nitella* aff. *cristata*), pondweed and milfoil vegetation almost completely replaced. In 2004, although *E. densa* was still dominant a narrow band of charophytes was sometimes present beyond the main depth extent of the weed beds, so that Native Condition and LakeSPI indices were slightly higher than the current scores. 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 pesticide (rotenone) removal of exotic fish. Re-establishment by extensive native vegetation was documented within 5 years of grass carp removal (Tanner et al. 1990a) and LakeSPI scores calculated at this time (1986-87) were close to the lakes estimated pristine condition. With the re-introduction of *E. densa* after 1996 (authors obs.), LakeSPI scores have since declined back to 1976 levels.

Table 55: LakeSPI results for Lake Parkinson.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	93	86	0
	1976	16	7.9	86
Historical data	1986	81	63	0
	1987	83	67	0
	2004	28	35	82
Present day	2010	23	29	82

3.5.5 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).

3.5.6 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.

3.5.7 Lake Taharoa

Lake condition:	Moderate
Stability:	Stable
Lake type:	Dune
Maximum depth:	11 m

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

LakeSPI scores over the last three surveys reflect compensating effects between a fluctuating Native Condition Index and Invasive Impact Index, with simultaneous reductions or increases in both indices leading to only moderate changes in the LakeSPI Index. In 2010, the depth extent of plants had recovered from a 1.5- 2.5 m retraction in 2007, when large amounts of unattached plants indicated a sustained reduction in the water clarity of the lake. Currently, the depth range is similar to that found in 2001 and 1983 (5-6 m).

Beneficial to this lake are features known to stabilise and protect lake ecological integrity including extensive native plants and associated seed banks, and large populations of filter-feeding mussels. These features may ensure that lake vegetation continues to withstand variable water clarity, particularly due to the storm events that have an impact on this exposed water body.

Table 58: LakeSPI results for Lake Taharoa.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine	1800s	100	100	0
	1983	45	64	67
Historical data	2001	41	53	70
	2007	39	46	63
Present day	2010	35	49	77

4. 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 89%. For the purposes of ranking and discussing these results, lakes have been categorised into five main groups based on the LakeSPI Index (Table 59), and are discussed in relation to lake type, as this often indicates geographic grouping and common pressures or impacts on the lakes.

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 North		89	75	0	Excellent
Rotopounamu		71	43	0	
Serpentine East		62	71	37	
Opouri		58	33	4.4	High
Rotoroa (Hamilton)		52	50	37	
Harihari		45	59	65	
Taupo		36	47	78	
Taharoa		35	49	77	
Otamatearoa		31	56	81	
Ngahewa		29	26	67	
Aratiatia		27	39	84	Moderate
Parkinson		23	29	82	
Rotoiti		23	25	84	
Rotoaira		23	27	90	
Parangi		22	11	75	
Puketi		21	18	85	
Ohakuri		14	10	96	
Arapuni		12	10	97	
Waipapa		12	9	96	
Atiamuri		11	3	99	Poor
Whakamaru		10	8	96	
Maraetai		9	3	97	
Karapiro		9	3	97	
Areare		0	0	0	
Hakanoa		0	0	0	
Hinemaiamai (B)		0	0	0	
Hotoananga		0	0	0	
Kainui (D)		0	0	0	
Kaituna		0	0	0	Non vegetated
Kimihia		0	0	0	
Koromatua		0	0	0	
Mangahia		0	0	0	
Mangakaware		0	0	0	
Maratoto		0	0	0	
Milicich		0	0	0	
Ngaroto		0	0	0	
Ohinewai		0	0	0	

Lake	Lake Type	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)	Overall condition
Okowhao		0	0	0	
Pataka		0	0	0	
Posa		0	0	0	
Rotokauri		0	0	0	
Rotokawau		0	0	0	
Rotomanuka		0	0	0	Non vegetated
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	

Peat Lakes

Peat lakes contained the largest group of lakes with 21 lakes surveyed for this report. Of these, 18 were classed as 'non-vegetated', two as 'high', and one was classed as 'excellent' (Table 59).

Lake Serpentine North remains the most notable of all lakes in this group, retaining close to its original pristine condition and ranked in 'excellent' overall condition. One of the most remarkable features of Lake Serpentine North is the absence of any of the more problematic invasive submerged weeds, such as *Egeria densa*, *Ceratophyllum demersum* and *Lagarosiphon major*. Absence of these weeds is likely to be a key factor in the lake having avoided the fate of permanent vegetation collapse that typically follows a period of weed domination, as observed in many other lakes. However, despite a high LakeSPI Index, the lake does show distinctive signs of stress. The impact of nutrient enrichment in the Serpentine Lakes (including Serpentine East) 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.

Two peat lakes, Lake Serpentine East and Lake Rotoroa are currently categorised as being in 'high' condition. Lake Serpentine East recently declined from 'excellent' to 'high' due to a slight reduction in native plant diversity and upon the new conspicuous invasion by an alien bladderwort *Utricularia gibba*. This invasive plant, also found in Lakes Serpentine South and Milicich in the Waikato, 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, and performs best in smaller, sheltered eutrophic lakes that possess other submerged vegetation. Although considered one of the more benign exotic weeds, *U. gibba* represents a smothering life-form that is suspected of excluding other plant species. It is a carnivorous plant that captures small aquatic organisms within trap-like bladders (Gordon and Pacheco 2007), so there may also be repercussions for nutrient cycling, food webs and ecosystem function in *U. gibba* dominated systems.

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 hand-weeding 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.

Eighteen of the twenty-nine 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. Most recently, reductions in submerged plant cover at three lakes since 2008 have led to their status dropping to 'non-vegetated'. The most significant of these changes was the widespread loss of well developed pondweed

vegetation at Lake Serpentine South, which previously had a high LakeSPI score of 86-87%. Lake Mangakaware also underwent retractions in depth limits and reductions in species diversity and plant covers, falling from being ranked as 'high' condition to 'non-vegetated'. At Lake Kainui, fluctuations in plant development that in 2005 led to a one-off assessment ranking the lake in 'moderate' condition, have now fallen with the lake returning to its previous 'non-vegetated' status. It is likely that the recovery of plants in 2005 was driven by a temporary reduction in the peat character of lake waters rather than a significant improvement in lake condition and therefore the subsequent return to 'non-vegetated' status may not signal significant deterioration in lake condition.

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 vegetation recovery should conditions improve to allow their re-establishment. 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 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 in downstream hydro lakes as their extent of colonisation is restricted more by water

flow than by water clarity and a more diverse assemblage of native species can co-exist with the weeds under these conditions.

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 seven of the dune lakes were ranked in 'moderate' overall condition, and although all contained submerged vegetation, they were all impacted to a significant degree by invasive plant species (Invasive Impact scores >60%). 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 range occupied by *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. *Ceratophyllum demersum*, dominated Lake Otamatearoa from the late 1990s onwards and led to the previous 'poor' classification of this lake. Currently, dominance of this weed has been reduced by the herbicide endothall, a selective herbicide which has elsewhere been shown capable of removing weeds with little impact on native vegetation. As a consequence of treatment, weed impact has decreased and native character has increased so the condition of Lake Otamatearoa is now reassessed as 'moderate'. However, in the absence of ongoing management of *C. demersum* we would expect the lake to return to a 'poor' condition.

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 most degraded state of a lake, where water quality conditions have deteriorated to the point where growth of submerged plants can no longer be supported.

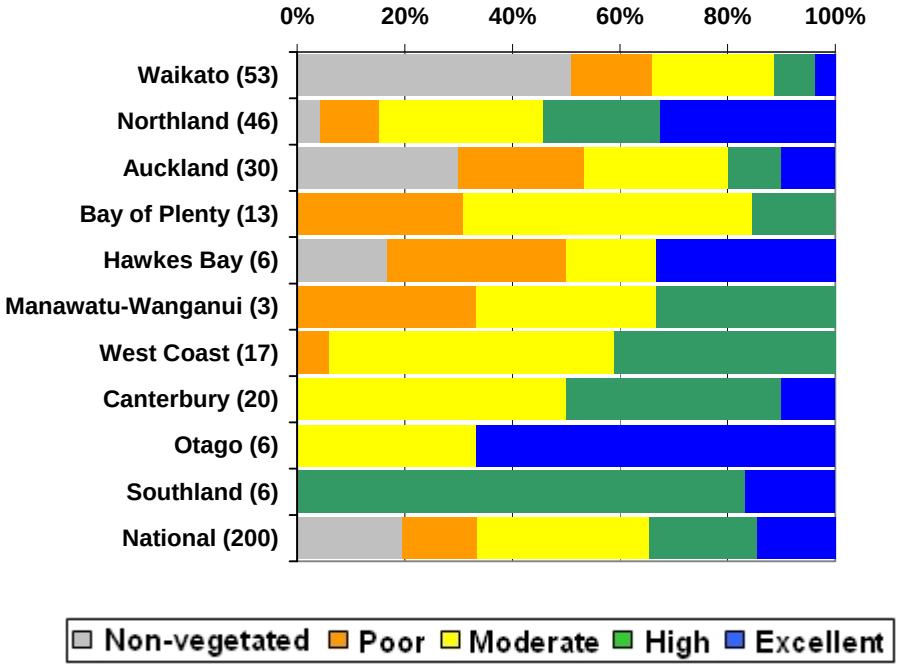


Figure 11: Proportions of lakes that fall into the five LakeSPI categories, showing total and regional differences, with number of lakes shown in parenthesis.

A smaller proportion of Waikato lakes fall into the 'poor' category, due to 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. Nationally, most lakes 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. Lake Serpentine North, a small peat lake is the only Waikato lake categorised as being in 'excellent' condition and, remains close to its maximum ecological condition expected for a lake of this type.

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, peat lakes, sensitive to changes in their catchments and other disturbance factors. 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.

5. 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. We would suggest that this schedule address:

    - **Lake Taupo**. Despite the importance to the region of this iconic lake, LakeSPI indices are only indicative at this stage as a full LakeSPI survey has not been undertaken. It is recommended that the lake be surveyed to provide an accurate present day assessment and indications of trends to date.

    - **Lake Rotopounamu**. Resurvey 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 change in natural condition.

    - **New lakes**. Lakes that have not yet been investigated and where submerged vegetation resources is likely to be present (e.g., additional dune, volcanic, artificial and karst lakes) should be prioritised (e.g., Lake Koraha). Representative non-vegetated lakes with the potential for recovery should also be considered (e.g., Lake Areare, Rotokauri).

    - **Restoration initiatives**. Baseline and re-surveys should be incorporated to monitor and document the impacts of restoration and other management initiatives (e.g., catchment nutrient mitigation, weed control measures).

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., Wildlands 2009).

6. Acknowledgments

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8. Appendix 1: List of plant species including marginal and emergent species for each lake, grouped by lake type. † = 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**	**22/04/2010**	**22/04/2010**	**14/11/1991**	**22/04/2010**	**1/02/2007**	**1/02/2007**	**1/02/2007**
Submerged species										
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 articulate			*					*		
Baumea sp.										
Baumea teretifolia										
Bolboschoenus fluviatilis										
†Callitriche stagnalis										
Carex secta								*	*	*

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**	**22/04/2010**	**22/04/2010**	**14/11/1991**	**22/04/2010**	**1/02/2007**	**1/02/2007**	**1/02/2007**
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	*	*					*	*	*	*	
†Galium palustre											

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
†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**	**20/04/2010**	**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 articulate		*					*		
Bolboschoenus fluviatilis									*
Eleocharis sphacelata	*	*					*		
†Juncus effuses									*
†Ludwigia palustris		*			*	*			*
†Ludwigia peploides	*	*		*					
†Lycopus europaeus	*								
†Myriophyllum aquaticum	*	*							*
†Paspalum distichum		*		*					
Persicaria decipiens		*							

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**	**20/04/2010**	**3/03/2008**	**15/02/2005**
†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 hyaline	*								
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
Survey date	**20/03/2008**	**08/03/2010**	**23/03/2009**	**20/04/2010**	**18/10/2004**	**18/10/2004**	**2104/2010**
Submerged species							
†*Ceratophyllum demersum*		*					
Chara australis		*	*			*	*
Chara fibrosa			*				
Chara globularis		*	*				*
†*Egeria densa*				*	*	*	
†*Elodea Canadensis*	*	*	*				*
Glossostigma elatinoides						*	
Glossostigma submersum						*	
†*Lagarosiphon major*							*
Lilaeopsis novaezelandiae						*	
Limosella lineate						*	
Myriophyllum pedunculatum						*	
Myriophyllum propinquum		*		*	*	*	
Myriophyllum triphyllum	*	*	*				*
Nitella aff. Cristata		*		*		*	*
Nitella hyaline		*	*				
Nitella pseudoflabellata			*		*	*	
Potamogeton cheesemannii		*	*	*	*	*	
†*Potamogeton crispus*							*
Potamogeton ochreatus	*		*				*

Lake	Parangi	Otamatearoa	Harihari	Parkinson	Rotoiti	Puketi	Taharoa
Survey 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 articulate		*	*		*	*	
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	*	*	*			*	*
Utricularia australis		*					