Environment Waikato Technical Report 2007/35

The Condition of 41 Lakes in the Waikato Region Using LakeSPI

www.ew.govt.nz
ISSN 1172-4005 (Print)
ISSN 1177-9284 (Online)

Environment Waikato
REGIONAL COUNCIL

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July 2007

Document #: 1208914

Peer reviewed by:
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Approved for release by:
David Speirs Date Jul 2007

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Executive Summary

NIWA was contracted by Environment Waikato to assess the condition of forty-one lakes using LakeSPI; a method that uses Submerged Plant Indicators (SPI) to assess, monitor and report on lake condition. LakeSPI assessments were carried out on each lake 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).

From the lakes assessed for this report, three lakes were classified in excellent condition (LakeSPI Index ≥80%); a further 14 lakes are in a satisfactory condition (impacted vegetation and/or weed invasion); 23 lakes were classified as unsatisfactory (devegetated, LakeSPI Index 0%) and the only hydro lake (Hinemaiaia B) was not suitable for LakeSPI assessment. Lakes were also considered according to their type as peat, riverine, volcanic or dune lakes.

The most notable of all the lakes were the three Serpentine (Rotopiko) Lakes, since they were the only lakes to have retained close to their original pristine condition and are ranked in "excellent" overall condition. Despite their high LakeSPI scores, it should be noted that these lakes still show distinctive signs of stress, consistent with the type of historical changes that are known to have taken place in most of the other lakes. Lake Rotoroa had the highest score of the "satisfactory" lakes, which may seem surprising, the results reflecting substantial regeneration of submerged native vegetation in recent years. Unfortunately this may be temporary, as an invasive weed species (*Egeria*) has re-established and will soon impact negatively upon lake condition. Of the remaining lakes in the "satisfactory" group, some had relatively sparse native vegetation and little or no impact by invasive species, while others had well developed vegetation that was dominated by invasive species.

All lakes have shown a significant reduction in LakeSPI scores from the pre 1900 'pristine' state. More of the peat and riverine lakes have deteriorated and 78%, of those in this study are currently devegetated. The dune and volcanic lakes of the region deteriorated more slowly and only one volcanic lake is now devegetated (Ngahewa).

LakeSPI enables the condition of small shallow water bodies to be compared with larger and deeper lakes (e.g., volcanic lakes). Although the latter have a greater buffering capacity against land use effects, recent impacts are associated with the widespread establishment of *Ceratophyllum demersum* (hornwort), the most invasive submerged weed in New Zealand.

LakeSPI indices for these Waikato lakes will provide valuable inter-lake comparisons and enable long term monitoring of future changes in their condition. For lake managers, LakeSPI provides relevant information for regional and national reporting requirements and can be used to help assess the effectiveness of catchment and lake management initiatives.

1. Introduction

1.1 Study brief

NIWA was contracted by Environment Waikato to assess the condition of forty-one lakes 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).

Lakes in the Waikato Region were chosen to develop and apply indicators. Phase 1 of the project included lakes for which NIWA held data and for which significant changes were not expected, therefore no site visits were required. This phase was completed in December 2003 (Edwards and Clayton 2003). Phase 2 included selected additional lakes that required surveys to provide an up-to date assessment and was completed by December 2005 (Edwards et al. 2005). Phase 3 has seen the addition of a further 12 lakes and brings the total of lakes reported here to forty-one.

The study brief also required all lakes to be placed into one of the following categories: “excellent”, “satisfactory” or “unsatisfactory” based upon their current day condition.

2. Background

2.1 History of the Waikato lakes

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

Prior to people arriving in New Zealand, the lakes would have been in their natural 'pristine' state. Periodic disruption to lake condition would have occurred with natural disturbances, such as volcanic activity, flood events or changes in the course of the Waikato River. Natural changes in lake condition also took place as the lakes aged, with key influences being changing climatic conditions, changes in catchment vegetation and progressive nutrient enrichment associated with increased productivity. Native submerged plant communities were present in all lake types as evidenced by early botanists. For example, Kirk (1871) reported an amazing 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 clear enough 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 species such as rudd, catfish and koi carp, which have contributed significantly to the deterioration in water quality and the decline of submerged vegetation. Exotic fish have collectively uprooted plants, disrupted bottom sediments and helped contribute to

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

Thirdly, there has been extensive invasion of most lakes by submerged weed species that have largely displaced native submerged vegetation. The earliest recorded introduction was *Elodea canadensis*, which arrived in New Zealand in the late 1800s and was subsequently spread around much of the country. Successively more competitive submerged weeds established in the Waikato lakes, firstly *Lagarosiphon major*, then *Egeria* 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, *Egeria* 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 subsequently reduces clarity to the point where aquatic plants have not re-established.

2.2 Lake vegetation changes

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

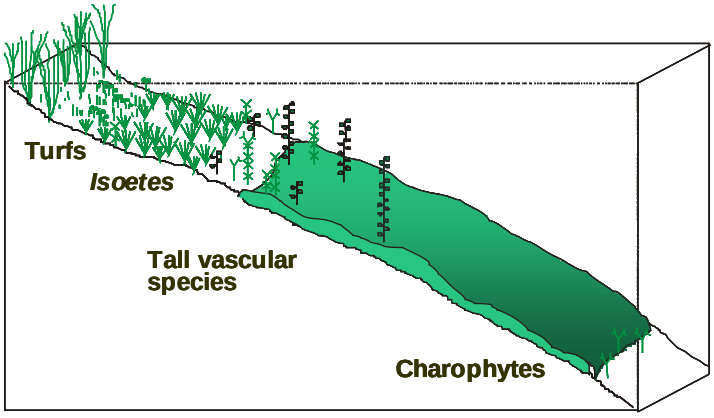


Figure 1: Depth profile illustrating the main components of native lake vegetation.

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

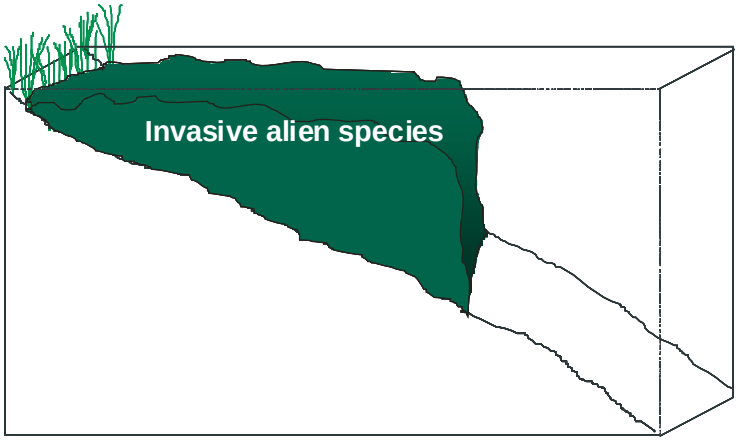


Figure 2: Depth profile illustrating the potential impact of invasive species.

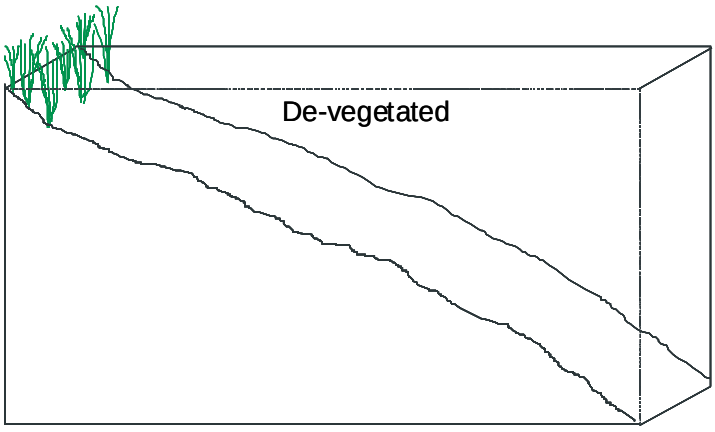


Figure 3: Depth profile illustrating a de-vegetated lake.

2.3 Plants as indicators of lake condition

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

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

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

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

3. Study methods

3.1 LakeSPI

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

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

- 'Invasive Condition 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 condition of a lake and provides an overall indication of lake condition. The higher the score the better the condition.

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

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

For full LakeSPI method details, the LakeSPI Technical Report and User Manual can be viewed at www.lakespi.niwa.co.nz

3.2 Baselines

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

1. Pristine condition

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

A 'pristine condition' baseline allows lake managers to compare present day lake condition with what the lake once would have been.

2. Historical condition

The LakeSPI method can be applied to available historic vegetation survey data using key vegetation information from macrophyte data in FBIS (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. Reference to historical LakeSPI scores allows changes over the last few decades to be followed.

3. Present day condition

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

3.3 Information sources

Data for the LakeSPI assessments have been collected from a variety of sources. Pristine condition was assessed using information reported by early botanists such as Kirk (1871) and Cunningham et al. (1953), where characteristics of vegetation structure and species composition were used to define a natural state for these lakes. Historical survey data was obtained from NIWA macrophyte data in FBIS and unpublished vegetation reports collated by Champion et al. (1993). Present day assessments were generated from recent LakeSPI surveys at these lakes, or, if lacking, from surveys conducted specifically for this project.

3.4 Study lakes

Forty-one lakes in total were selected for LakeSPI assessment. The location of lakes is indicated in Figure 4 and includes dune lakes along the West Coast, riverine lakes adjacent to the northern reach of the Waikato river, Peat influenced lakes within the Waikato basin and lakes within the Taupo volcanic zone. The lakes also vary in size and depth (Table 3.1).

Some lakes were not surveyed for this report because either they were known to be de-vegetated and recent recovery was unlikely (7 lakes), or recent information was available and no major changes were expected (3 lakes). The remaining 31 lakes were surveyed over late 2004 to 2007 (Table 3.1).

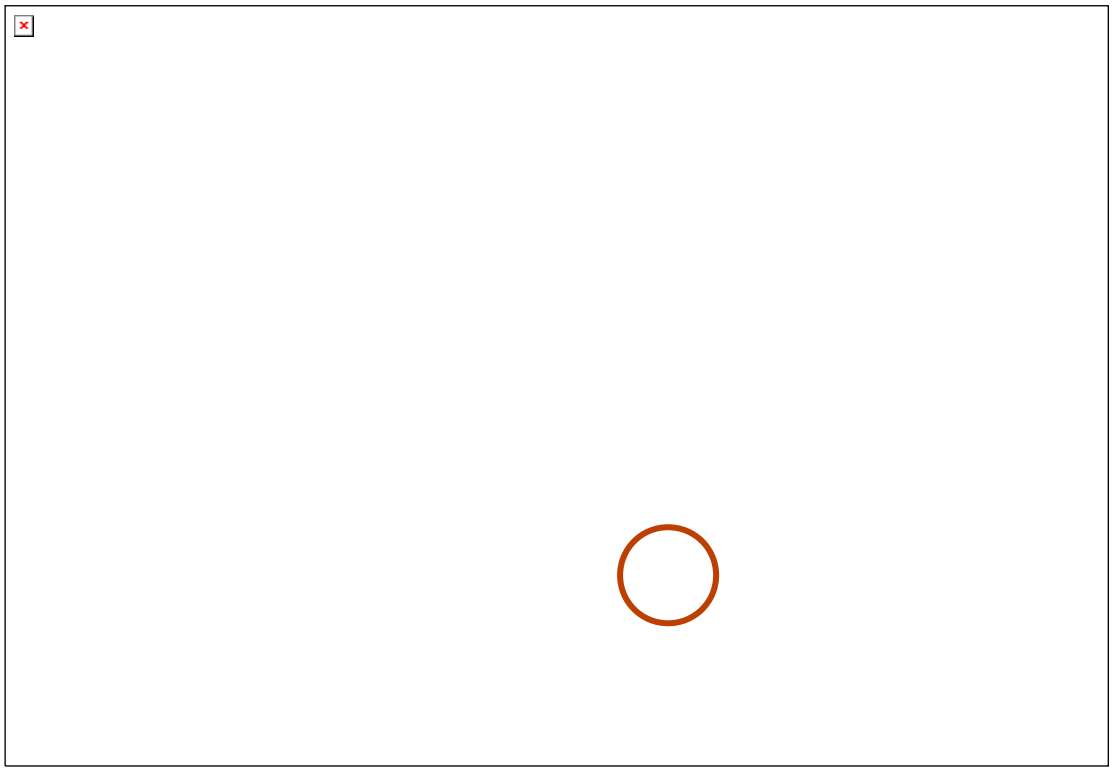


Figure 4: Location of lake groups within the Waikato Region; orange rings are dune lakes, green rings peat lakes, blue rings riverine lakes, red rings volcanic zone lakes and the pink arrow points to one hydro lake.

Table 3.1: Lake type, size (km^2) and depth (m) for forty-one lakes assessed using LakeSPI.

Lake	Lake Type	Size (km^2)	Depth (m)	Survey date
Areare		0.34	5.1	
Hakanoa		0.56	2.5	
Harihari		0.18	c. 8 m	01/11/2005
Hinemaiaia (B)		0.12	c.15	19/11/2004
Hotoananga		0.17	3	
Kainui (D)		0.32	6.7	24/05/2005
Kimihia		0.55	3.3	
Kaituna (B)		0.21	1.3	01/02/2007
Koromatua		0.068	1.2	01/02/2007
Mangakaware		0.12	4.8	25/05/2005
Mangahia		0.14	1.5	01/02/2007
Ngahewa		0.11	7.5	18/11/2004
Ngaroto		1.29	4	
Ohinewai		0.24	4.5	
Okowhao		0.17	2.2	24/05/2005
Opouri		0.26	25	18/11/2004
Otamatearoa		0.063	5	18/10/2004
Parkinson		0.019	8	18/10/2004
Pataka		0.057	5	21/06/2007
Posa		0.029	4	21/06/2007
Puketi		0.059	7	18/10/2004
Rotoaira		15.32	14.6	26/03/2007
Rotoiti		0.008	7	18/10/2004
Rotokauri		0.55	4	
Rotomanuka		0.17	8.7	21/06/2007
Rotongaro		3.32	3.3	24/05/2005
Rotongaroiti		0.53	2*	25/05/2005
Rotokawau		0.32	1.2	18/06/2007
Serpentine East		0.016	4.4	02/09/2005
Serpentine North		0.053	4	02/09/2005
Serpentine South		0.083	3.6	02/09/2005
Rotopounamu		5.54	7.9	19/11/2004
Rotoroa (Hamilton)		0.54	6	
Ruatuna		0.17	3.2	21/06/2007
Taharoa		2.05	9.2	17/04/2007
Taupo		622.63	162.8	
Tunawhakpeka (E)		0.08	1	18/06/2007
Tutaeinanga		0.031	3	18/11/2004
Waahi		5.37	5	28/10/2005

Waikare		34.42	2	
Whangape		11.97	2.7	15/02/2005

*Decreased to c. 0.5 m by 2005.

Key to lake types	Peat	Riverine	Volcanic/tectonic	Hydro	Dune

4. Results

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

HIGHER LakeSPI Index = Better lake condition.

HIGHER Native Condition Index = Better lake condition.

LOWER Invasive Condition Index = Better lake condition.

A lake with a LakeSPI Index of 0 has insufficient plants (plant cover <10%) to generate meaningful LakeSPI scores.

4.1 Lake Areare

Lake type: Peat lake
Current vegetation status: De-vegetated

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 extreme peat stained nature of the lake and absence of major land-use changes since then.

Table 4.1: LakeSPI results for Lake Areare.

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

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

4.2 Lake Hakanoa

Lake type: Riverine
Current vegetation status: De-vegetated

Surface reaching weed beds of *Egeria*, 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 the 1973 survey 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 that it remains de-vegetated.

Table 4.2: LakeSPI results for Lake Hakanoa.

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

* Anticipated score

4.3 Lake Harihari

Lake type: Dune
Current vegetation status: Vegetated

There is no historical vegetation data for Lake Harihari. During the current assessment, *Elodea canadensis* was widespread but did not dominate the vegetation. A rich assemblage of native plants was present. The other invasive species *Potamogeton crispus* and *Juncus bulbosus* were uncommon, and probably originated from seed introduced via wildfowl.

Table 4.3: LakeSPI results for Lake Harihari.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Condition Index (%)
Pristine	1800s	93	86	0
Present day	2005	50	61	58

4.4 Lake Hinemaiaia (B)

Lake type: Artificial lake
Current vegetation status: Sparsely vegetated

This dammed watercourse had low and patchy vegetation cover from surveys for this study and is a poor environment for plant growth due to sediment instability, occasional turbid flows and frequent disturbance. It is the lower of three dammed water bodies in a hydro-scheme constructed from 1939 and there is no previous information on the submerged vegetation. It was not considered appropriate to apply the LakeSPI method or to calculate a 'pristine condition'.

4.5 Lake Hotoananga

Lake type: Peat lake
Current vegetation status: De-vegetated

Egeria 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 a degraded but stable condition. No submerged plants were found in the 2001 LakeSPI survey despite the good water clarity noted by divers at time.

Table 4.4: LakeSPI results for Lake Hotoananga.

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

4.6 Lake Kainui (D)

Lake type: Peat
Current vegetation status: Vegetated

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

Table 4.5: LakeSPI results for Lake Kainui (Lake D)

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Condition Index (%)
Pristine	1800s	95	90	0
Historical data	1983	0	0	0
	1991	0	0	0
Present day	2005‡	74	47	0

‡ Based on 3 out of 5 sites where cover exceeded 10% threshold.

4.7 Lake Kimihia

Lake type: Riverine
Current vegetation status: De-vegetated

In 1958 Mason and Moar collected *Egeria* from Lake Kimihia, and suggested this infestation was the primary source for *Egeria* 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.

Table 4.6: LakeSPI results for Lake Kimihia.

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

* Anticipated score

4.8 Lake Kaituna (B)

Lake type: Peat
Current vegetation status: De-vegetated

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 4.7: LakeSPI results for Lake Kaituna.

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

4.9 Lake Koromatua

Lake type: Peat
Current vegetation status: De-vegetated

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 4.8: LakeSPI results for Lake Koromatua.

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

4.10 Lake Mangakaware

Lake type: Peat
Current vegetation status: Vegetated

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

Table 4.9: LakeSPI results for Lake Mangakaware.

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

4.11 Lake Mangahia

Lake type: Peat
Current vegetation status: De-vegetated

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.

Table 4.10: LakeSPI results for Lake Mangahia.

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

4.12 Lake Ngahewa

Lake type: Volcanic
Current vegetation status: De-vegetated

This lake has lost the beds of invasive *Lagarosiphon major* recorded in 1989 and is now essentially de-vegetated.

Table 4.11: LakeSPI results for Lake Ngahewa.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Condition Index (%)
Pristine	1800s	90	81	0
Historical data	1973	78	57	0
	1989	15	4.8	81
Present day	2004	0	0	0

4.13 Lake Ngaroto

Lake type: Peat lake
Current vegetation status: De-vegetated

Lake Ngaroto has a history of submerged weed problems and *Elodea canadensis* and *Ceratophyllum demersum* were first identified from the lake in 1968-1969 (Champion et al. 1993). LakeSPI results for historic 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 4.12: LakeSPI results for Lake Ngaroto.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Condition 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

* Anticipated score

4.14 Lake Ohinewai

Lake type: Riverine
Current vegetation status: De-vegetated

During a survey of Lake Ohinewai in 1981, *Egeria* 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 in Lake Ohinewai.

Table 4.13: LakeSPI results for Lake Ohinewai.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Condition Index (%)
Pristine	1800s	97	93	0
Historical data	1958	97	93	0
	1981	26	27	85
	1983	11	0	93
	1991	0	0	0
Present day	2003*	0	0	0

* Anticipated score

4.15 Lake Okowhao

Lake type: Riverine
Current vegetation status: De-vegetated

This lake is now de-vegetated following a period of dominance by the invasive weed *Egeria* from at least 1981 to 1991.

Table 4.14: LakeSPI results for Lake Okowhao.

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

4.16 Lake Opouri

Lake type: Volcanic
Current vegetation status: Vegetated

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 Condition Index dropped, leading to a higher LakeSPI score in 2004. This lake vegetation appears to be unstable, and may well have similarities to nearby Lake Okaro, where shallow-water anoxia has apparently caused root death and detachment of *E. canadensis* shoots at various intervals (Clayton et al. 2005).

Table 4.15: LakeSPI results for Lake Opouri.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Condition Index (%)
Pristine	1800s	88	80	0
Historical data	1984	34	30	54
	1989	30	23	62
Present day	2004	58	33	4.4

4.17 Lake Otamatearoa

Lake type: Dune
Current vegetation status: Vegetated - invaded

The low present day LakeSPI Index reflects the presence of *Ceratophyllum demersum*, the most invasive weed, which was introduced some time after 1996. However, *C. demersum* plants appeared to be stunted and areas that were not invaded still supported remnant charophytes and the invasive species *Elodea canadensis*, which has been present since at least 1950 (Cunningham et al. 1953). Outside of the LakeSPI profile sites we observed the threatened plants *Myriophyllum robustum*, *Ranunculus macropus* and a *Utricularia* species (possibly *U. australis*) amongst the emergent vegetation around the lake margin.

Table 4.16: LakeSPI results for Lake Otamatearoa.

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

4.18 Lake Parkinson

Lake type: Dune
Current vegetation status: Vegetated - invaded

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

Table 4.17: LakeSPI results for Lake Parkinson.

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

4.19 Lake Pataka

Lake type: Peat lake
Current vegetation status: De-vegetated

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 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, current lake vegetation would be responsive to any improvements in water quality afforded by initiatives underway including fencing the lake margin and riparian plantings.

Table 4.18: LakeSPI results for Lake Pataka.

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

4.20 Lake Posa

Lake type: Peat lake
Current vegetation status: De-vegetated

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 4.19: LakeSPI results for Lake Posa.

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

4.21 Lake Puketi

Lake type: Dune
Current vegetation status: Vegetated - invaded

This lake has been dominated by the invasive weed *Egeria* for at least 17 years and the LakeSPI Index of 21% is reduced by the high Invasive Condition 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).

Table 4.20: LakeSPI results for Lake Puketi.

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

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

4.22 Lake Rotoaira

Lake type: Taupo volcanic zone
Current vegetation status: Vegetated

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 Condition 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 4.21: LakeSPI results for Lake Rotoaira.

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

4.23 Lake Rotoiti

Lake type: Dune
Current vegetation status: Vegetated - invaded

The invasive weed, *Egeria*, 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 4.22: LakeSPI results for Lake Rotoiti.

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

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

4.24 Lake Rotokauri

Lake type: Peat lake
Current vegetation status: De-vegetated

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* 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 *Egeria* weed beds still dominated the lake (Champion et al. 1993), but native vegetation (Native Condition Index) and overall LakeSPI scores had declined. *Egeria* 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 since then is unlikely given the hypertrophic status of this lake.

Table 4.23: LakeSPI results for Lake Rotokauri.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Condition 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	14	7	93
Present day	2003*	0	0	0

* Anticipated score

4.25 Lake Rotokawau

Lake type: Peat lake
Current vegetation status: De-vegetated

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 an 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 4.24: LakeSPI results for Lake Rotokawau.

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

4.26 Lake Rotomanuka

Lake type: Peat lake
Current vegetation status: De-vegetated

By 1983 *Egeria* had reached its full potential in Lake Rotomanuka as indicated by a LakeSPI Invasive Condition Index of greater than 90% and native plant species were found in small shallow pockets only. The more recent LakeSPI surveys found no submerged plants growing in Lake Rotomanuka.

Table 4.25: LakeSPI results for Lake Rotomanuka.

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

4.27 Lake Rotongaro

Lake type: Riverine
Current vegetation status: De-vegetated

Lake Rotongaro is presently de-vegetated and turbid. Previously it was known to support variable beds of the invasive weed, *Egeria*, 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 4.26: LakeSPI results for Lake Rotongaro.

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

4.28 Lake Rotongaroiti

Lake type: Riverine
Current vegetation status: De-vegetated

Egeria 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, a total of only two plants were recorded from the five sites investigated and today the lake remains in a de-vegetated state.

Table 4.27: LakeSPI results for Lake Rotongaroiti.

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

[ϕ] Sparse vegetation (cover <10%)

4.29 Lake Rotopounamu

Lake type: Taupo volcanic zone
Current vegetation status: Vegetated

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 complete loss of charophytes. 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 4.28: LakeSPI results for Lake Rotopounamu.

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

4.30 Lake Rotoroa

Lake type: Peat lake
Current vegetation status: Vegetated

Lake Rotoroa provides an interesting array of LakeSPI indices as the lake has a detailed history of invasive weed problems followed by a period of no submerged vegetation and currently supports a healthy native plant community. Recent LakeSPI indices show that Lake Rotoroa scores nearly 75% of its maximum potential lake condition and has improved considerably from its devegetated state. However, the discovery of *Egeria* at one location in November 2002 is of concern, as development of this species will detrimentally impact upon lake condition. Since then *Egeria* plants have continued to expand and will reduce any future LakeSPI indices.

Table 4.29: LakeSPI results for Lake Rotoroa.

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

4.31 Lake Ruatuna

Lake type: Peat lake
Current vegetation status: De-vegetated

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 must have existed in a better condition in the 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 4.30: LakeSPI results for Lake Ruatuna.

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

4.32 Lake Serpentine East (Rotopiko East)

Lake type: Peat lake
Current vegetation status: Vegetated – all native.

Lake Serpentine East together with Lake Serpentine North currently represent the highest scoring lakes in the Waikato Region with a LakeSPI Index of ≥90%, being one of the only remaining Waikato lakes to remain un-impacted by invasive plant species. The high score is driven by presence of well developed, solely native vegetation, dominated by pondweeds (*Potamogeton* spp.) and charophytes. Lake Serpentine East currently has a LakeSPI Index of 91% indicating that it is still close to its maximum scoring potential.

Table 4.31: LakeSPI results for Lake Serpentine East.

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

4.33 Lake Serpentine North (Rotopiko North)

Lake type: Peat lake
Current vegetation status: Vegetated – all native.

Lake Serpentine North together with Lake Serpentine East currently represent the highest scoring lakes in the Waikato Region with a LakeSPI Index of ≥90%. Lake Serpentine North differs from Lake Serpentine East in that it has greater coverage of plants, mostly charophytes, often down to a greater depth. Although LakeSPI indices show excellent lake condition, there are signs that the submerged vegetation is under stress (e.g., high abundance of periphytic algal growth attached to plant surfaces) and that there is a risk of rapid decline in plant cover.

Table 4.32: LakeSPI results for Lake Serpentine North.

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

4.34 Lake Serpentine South (Rotopiko South)

Lake type: Peat lake
Current vegetation status: Vegetated – all native

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. Most recently (2005 to 2007), an expansion in the cover of the native pondweed means that the lake now scores a relatively high LakeSPI Index value of 86%. It is thought likely that this plant development is in response to measures to control exotic fish populations (mostly rudd), but is not known if it will be sustained. Pondweeds often have a marked seasonality in growth and also between years, which would result in variation in LakeSPI scores where these species occur.

Table 4.33: LakeSPI results for Lake Serpentine South.

State	Year	LakeSPI Index (%)	Native Plant Index (%)	Invasive Plant Index (%)
Pristine	1800s	97	93	0
Historical data	1991[ϕ]	0	0	0
	2005[‡]	70	67	0
Present day	2007	86	68	0

[ϕ] Sparse vegetation (cover <10%); [‡] Based on four sites where plant cover exceeded 10%.

4.35 Lake Taharoa

Lake type: West Coast sand dune
Current vegetation status: Vegetated

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

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

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

Table 4.34: LakeSPI results for Lake Taharoa.

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

4.36 Lake Taupo

Lake type: Taupo volcanic zone
Current vegetation status: Vegetated

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 4.35: LakeSPI results for Lake Taupo.

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

4.37 Lake Tunawhakapeka (E)

Lake type: Peat lake
Current vegetation status: De-vegetated

This lake was extremely shallow at the time of the 2007 survey (most sites <0.5 m) and would have been somewhat deeper in the past. But, as a shallow lake, it is very likely to have supported an 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 4.36: LakeSPI results for Lake Tunawhakapeka (E)

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

4.38 Lake Tutaeinanga

Lake type: Volcanic
Current vegetation status: Vegetated

No historical data are available. The present day survey found this shallow (3 m) lake was partially invaded (2/5 sites) by *Egeria*, yet still had some areas of native vegetation that contributed to a moderate LakeSPI Index.

Table 4.37: LakeSPI results for Lake Tutaeinanga.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Condition Index (%)
Pristine	1800s	94	87	0
Present day	2004	65	56	23

4.39 Lake Waahi

Lake type: Riverine
Current vegetation status: De-vegetated

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

Table 4.38: LakeSPI results for Lake Waahi.

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

4.40 Lake Waikare

Lake type: Riverine
Current vegetation status: De-vegetated

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* 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 4.39: LakeSPI results for Lake Waikare.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Condition Index (%)
Pristine	1800s	100	100	0
Historical data	1871	100	100	0
	1978	24	29	85
	1984	0	0	0
	1992	0	0	0
	1993	0	0	0
	2001	0	0	0
Present day	2003*	0	0	0

* Anticipated score

4.41 Lake Whangape

Lake type: Riverine
Current vegetation status: De-vegetated

Today, Lake Whangape remains in a highly impacted condition as 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 4.40: LakeSPI results for Lake Whangape.

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

5. Discussion

LakeSPI was used to assess the condition of the Waikato lakes as it enables changes in lake condition to be assessed and monitored over long periods. LakeSPI indices are generated and presented on a scale ranging from 0-100%, the latter representing the maximum scoring potential of any one lake. By presenting the LakeSPI indices in this way, the method enables changes in lake condition over time to be detected and also allows for comparisons to be made between dissimilar lakes within or between different regions. Other benefits of this approach include the ability to retrospectively establish LakeSPI indices from historical survey data so that the scale and speed of any changes in lake condition can be illustrated. It also allows for lakes to be classified based on lake condition.

One limiting factor of this study is that many of the lakes have insufficient data available to ensure appropriate selection of LakeSPI sites (e.g., historical investigations at limited number of sites, including those not suitable for the LakeSPI method). A full LakeSPI survey recommends that 5 baseline sites be selected from around each lake to ensure a fair representation of vegetation features and community composition. Ideally, these same baseline sites would be repeated during consecutive surveys. For historical records this was not possible and even present day records for most of these lakes had no baseline sites established. 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.

Each of the lakes in this study was considered in relation to lake type. Peat and riverine lakes contained the largest group of lakes and are discussed together since they share many common properties in terms of depth, catchment influences and vulnerability to change. Of this combined group of twenty-eight lakes, twenty-two were classed as ‘unsatisfactory’, three as ‘satisfactory’, and three were classed as ‘excellent’ (Table 5.1).

The most notable of all the lakes in this group are the Serpentine Lakes,, the only lakes to retain close to their original pristine condition. They are ranked in “excellent” overall condition. However, despite their high LakeSPI indices, these lakes show distinctive signs of stress, similar to historical changes that took place before vegetation collapse in other lakes. The impact of nutrient enrichment in the Serpentine Lakes is apparent with most plants having seasonally high abundance of periphytic algal growth attached to the plant surfaces. Herbivorous rudd (*Scardinius erythrophthalmus*) were found in these lakes and an intensive coarse fish removal programme was implemented by management agencies. Fish control works in

Serpentine South are considered most likely responsible for the recent recovery of native submerged plants there, and provide further evidence for impacts by exotic fish. One of the most remarkable features of the Serpentine Lakes is the absence of any problematic invasive submerged weeds. This is likely to be a key factor in these lakes having avoided the fate of vegetation collapse that typically follows a period of domination by weeds, such as *Egeria*, as observed in most other lakes.

There were three lakes in this peat and riverine group classed as 'satisfactory', and they were all peat lakes (i.e., Rotoroa, Kainui and Mangakaware). The most notable of these is Lake Rotoroa. The overall condition of Lake Rotoroa is the highest of the 'satisfactory' lakes, being 75% of its estimated pristine condition. This result reflects the substantial regeneration of submerged native vegetation that has taken place in recent years. Unfortunately this is likely to be of a temporary nature as an invasive weed species (*Egeria*) has recently established (de Winton et al. 2003) and expansion of this weed is likely to impact negatively on lake condition in the future. The lake went through all of 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. Of the two other peat lakes in a 'satisfactory' state, Lakes Kainui (D) had no invasive species, but the plant cover was low and LakeSPI scores was based on less than five sites where native vegetation cover exceeded the 10% threshold. Slight fluctuations in future plant development would have a significant influence on these scores and therefore the results should be considered indicative only.

Twenty-two of the twenty-three lakes in the 'unsatisfactory' category were peat and riverine lakes and were either devoid of submerged vegetation or covers did not exceed the 10% threshold for LakeSPI. 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.

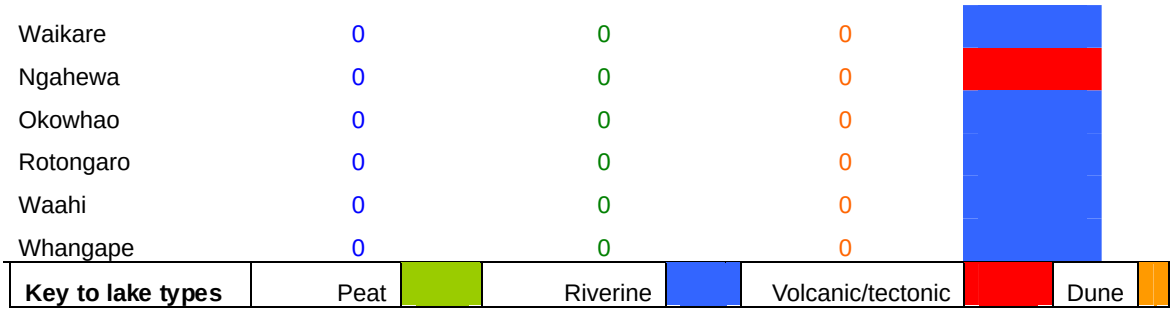
All of the dune lakes were classed as 'satisfactory', but they fell in the lower range of satisfactory due to significant impacts from invasive plant species that reduced LakeSPI scores to ≤50% of pristine condition. Lake Harihari was the highest ranked of the dune lakes, and only had the relatively benign weed *Elodea canadensis* recorded. This lake also retained significant deep-water charophyte beds beyond the main depth of impact from *E. canadensis*. Lake Taharoa has been colonised by *Lagarosiphon major* in addition to *Elodea*, and also shows signs of vegetation instability. Historical descriptions from the1950s (Cunningham et al. 1953) exist for several dune lakes in such as Lake Otamatearoa and Thompsons Lake. 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 lakes were gathered from the 1970s or 1980s onwards.

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. All but one of the lakes was classed as 'satisfactory', with Lake Rotopounamu the highest ranked because of the absence of any 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 well be a temporary phenomenon; however it is not known whether native charophyte seed banks have been buried too deeply to enable rapid recovery. Overall, these volcanic lakes are more likely to retain remnants of their original vegetation, especially in the shallow and deep water zones. Wind-generated wave action in large lakes creates a shallow-water disturbance zone that is often dominated by a diverse assemblage of low-growing, turf-forming, native species, such as documented for Lake Rotoaira. The mid-depth zone is where invasive weed species have the greatest impact. In the past, native charophytes grew in deeper water beyond the displacement influence of invasive weed species, however the recent establishment of *Ceratophyllum demersum* (hornwort) is now leading to widespread loss of native charophyte meadows in deeper water. The relatively low LakeSPI ranking of Lakes Rotoaira and in particular Taupo are attributable to the extensive impact that hornwort has had on submerged vegetation.

Table 5.1: Summary of current LakeSPI indices, excluding Lake Hinemaiaia.

Lake	LakeSPI Index (%)	Native Index (%)	Invasive Index (%)	Lake Type
Excellent				
Rotopiko North	93	83	0	
Rotopiko East	91	80	0	
Rotopiko South	86	68	0	
Satisfactory				
Rotoroa (Hamilton)	75	50	0	
Kainui (D)	74	47	0	
Rotopounamu	71	43	0	
Tutaeinanga	65	56	23	
Mangakaware	63	65	33	
Opouri	58	33	4.4	
Harihari	50	61	58	
Taharoa	39	46	63	
Taupo	36	47	78	
Parkinson	28	35	82	
Otamatearoa	23	43	90	
Rotoiti	23	25	84	
Rotoaira	23	27	90	
Puketi	21	18	85	
Unsatisfactory				
Areare	0	0	0	
Hotoananga	0	0	0	
Kaituna	0	0	0	
Koromatua	0	0	0	
Mangahia	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	
Tunawhakapeka (E)	0	0	0	
Hakanoa	0	0	0	
Kimihia	0	0	0	
Ohinewai	0	0	0	
Rotongaroiti	0	0	0	

Waikare	0	0	0
Ngahewa	0	0	0
Okowhao	0	0	0
Rotongaro	0	0	0
Waahi	0	0	0
Whangape	0	0	0



For lake managers, LakeSPI provides relevant information for regional and national reporting requirements, including operational monitoring and state of the environment reporting. Over time the results can be used to assess the effectiveness of catchment and lake management initiatives.

The results presented in this report are more accurate for current lake condition, compared to past lake condition which is often based on minimal information. For most of the devegetated peat and riverine lakes there was no merit in establishing baseline sites for long-term monitoring. The establishment of baseline sites for other lakes where current information was available was beyond the scope of this study. However, it is recommended that baseline sites be established for Lakes Taupo for more accurate present day assessment and for long-term future monitoring. LakeSPI indices on the Waikato lakes have provided valuable inter-lake comparisons and information on historical changes. Continued long-term monitoring is recommended for identifying future changes in the condition of these lakes.

6. Recommendations

- It is recommended that that baseline sites be established for Lakes Taupo for more accurate present day assessment and for long-term future monitoring.

- Resurvey Lake Rotopounamu in late summer 2008 and assess charophyte recovery, potential for seed bank reactivation in the absence of natural recovery, and repeat LakeSPI assessment to reflect natural condition if native vegetation recovery is widespread.

- Carry out a spot check on several selected lakes where it was assumed that they would have remained in a devegetated state since their previous assessment (e.g., Lakes Hotoananga and Rotokauri).

- Lakes where there may be some potential for natural or facilitated restoration works (e.g., Lakes Pataka, Kaituna and Rotomanuka) should be included in a monitoring schedule for resurvey after 5 years or as indicated by other ecological or water quality changes.

- Use LakeSPI information on Waikato lakes to identify candidate lakes for potential protection of restoration.

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