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Waikato region shallow lakes management plan: Volume 2

Shallow lakes resource statement: Current status and future management recommendations

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Abstract

This document is the second part of Waikato Regional Council's Shallow Lake Management Plan. It has been developed as a resource statement (to accompany Volume I) that summarises available information and knowledge about the condition of shallow lakes in the Waikato region and identifies specific management recommendations for individual lakes.

Volume I of the Shallow Lakes Management Plan summaries the statutory and policy framework for shallow lake management, and identifies the key management issues for shallow lakes in the Waikato region, with a specific focus on matters that WRC has responsibility for. Nine objectives and a suite of associated management strategies have been identified in Volume I to guide implementation over the next 10 years.

1 Introduction

The Waikato region contains 96 lakes greater than 1 ha in size. Seventy (71) of these are shallow lakes with a maximum depth of 10m or less.

Figure 1 Location of lake groups within the Waikato region

Shallow lakes are found throughout the region, having formed in conjunction with the Waikato River system, the region's coast and cave systems, and the formerly extensive peat bogs of the region (Figure 1). Shallow lake 'hotspots' occur in the Waikato (peat, riverine, dune and karst lake types), Waipa (mostly peat lakes) and Waitomo Districts (mostly dune lakes) as shown in Figure 2.

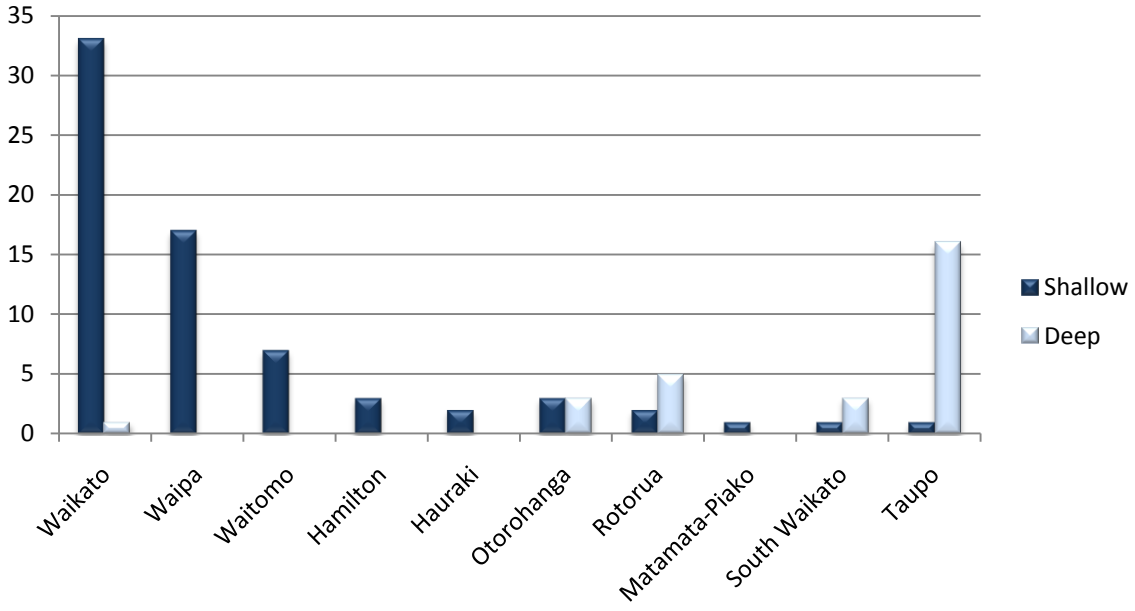


Figure 2 The number of shallow and deep lakes within districts in the Waikato region

This resource statement summarises available information about the current status of shallow lakes in the Waikato region, and identifies future management recommendations on a lake-by-lake basis. It has been prepared to accompany the Shallow Lakes Management Plan: Volume I, which identifies objectives and priorities for Waikato Regional Council's shallow lake management programme over the next 10 years.

1.1 Shallow lake information

Information for this resource statement has been sourced from a number of reports, databases and records that have been compiled by various agencies and individuals over several decades.

In the 1980's, the Waikato Valley Authority undertook several surveys of small lakes that focused on the usage, water quality and trophic status of 38 lakes within the region. The findings were published as a series of technical reports prepared by Town (1980, 1982b), Davenport (1981), and Boswell et al. (1985).

In 1996, Hamill (1996 a,b,c) reviewed Waikato Regional Council's lake water quality monitoring programmes and data, and (i) assessed its adequacy for detecting environmental trends; (ii) recommended future monitoring and information requirements; and (iii) compiled a comprehensive bibliography of information for 41 regional lakes. This work concluded that the Council had undertaken water quality monitoring on a sporadic and ad hoc basis, and that relevant information was lacking about individual lake dynamics and characteristics. As a result, it recommended that information be compiled for each lake to identify information gaps, and that monitoring programmes be established to meet clear objectives, and determine long term water quality trends. Hamill also suggested modifications to monitoring protocols that were subsequently incorporated into Waikato Regional Council's Lake Monitoring Programme.

In 1997, an information strategy was prepared for lakes in the Waikato region, to provide strategic guidance regarding Council's role in gathering, storage, and dissemination of information about the region's lakes (Edgar, 1997). The strategy was founded within the context of an ecosystem-based approach, and the requirements of the (then-proposed) Waikato Regional Policy Statement – including objectives and policies for the protection

of water quality; outstanding waterbodies and valued attributes of other waterbodies; and improved riparian management. The information strategy (Edgar 1997) also refers to several shallow lake projects that Waikato Regional Council was undertaking (or party to) at that time, including: preparation of rehabilitation plans for several peat lakes in the Waipa District; development of a lake-care group at Lake Cameron; and development of a prioritisation system for lakes in the Waipa district.

To underpin the implementation of the Waikato Regional Policy Statement (RPS), Taylor et al. (2001, 2004) subsequently established projects to identify "outstanding water bodies" of the region. Lakes Rotopounamu, Whangape, Serpentine, Maratoto, and Taharoa were identified to be "outstanding waterbodies" on the basis of available information at that time.

In addition to the documents described above, an array of separate reports and publications provide specific details, and summarise available monitoring information for many of the region's lakes, and are included in the bibliography. Collectively, these reports have and continue to be used to guide the Council's management and resource allocation decisions.

2 Condition of shallow lakes

The Waikato region's shallow lakes make up a large proportion of the 30% of New Zealand lakes that have been categorised as having poor to extremely poor water quality, having undergone substantial declines in ecological condition (Hamilton et al. 2010, Hamill 2006). Many of these lakes have shifted from a clear-water macrophyte-dominated state to a turbid, phytoplankton-dominated state.

The following factors have been identified as contributing to the ongoing decline of the health and wellbeing of many shallow lakes in the Waikato region (from NIWA 2010):

- High loads of diffuse contaminant inputs of nutrients, sediment and bacteria from catchment run-off and livestock access to the lakes;
- Internal regeneration of nutrients from sediment re-suspension (by wind action or pest fish) and/or release of nutrients as a result of low oxygen events at the lakebed;
- High abundance of pest fish (e.g., koi carp and catfish), and/or aquatic weeds (willow, alligator weed, oxygen weed, hornwort);
- Reduced water depth due to drainage and/or reduced flushing due to water control structures and artificial regimes such as the Lower Waikato Flood Control scheme;
- Past development of large exotic weed beds that create deoxygenation events and often precede a switch to turbid, nutrient enriched conditions; and
- Removal of vegetation filtering potential in the catchment through drainage of marginal wetland vegetation, agricultural development and grazing access.

Whilst these issues affect many of the lakes within the Waikato River catchment, some shallow lakes have not been affected to the same extent and maintain a greater degree of natural character.

This section summarises available information about the current state of shallow lakes, as well as the restoration and management actions that have been undertaken at them.

2.1 Lake water quality

Waikato Regional Council has two main lake monitoring programmes that collect information about the water quality of shallow lakes.

The first is a lake water quality/trophic state monitoring programme that monitors water quality parameters bimonthly in 8 shallow lakes (Lakes Waahi, Whangape, Waikare, Serpentine North, Serpentine East, Maratoto, Rotomanuka, Hakanoa) These lakes have been monitored consistently for between 10 and 17 years, providing valuable information about the inherent variability of lake water quality and long term water quality trends for these sites. The variables monitored include: temperature; dissolved oxygen; dissolved reactive and total phosphorus; dissolved inorganic nitrogen species and total nitrogen; chlorophyll *a*; and suspended solids.

Lake trophic state is assessed using trophic level index (TLI) values that are calculated according to the methods described by Burns et al. (2000) involving commonly measured lake variables, including chlorophyll a (Chla), secchi depth, total phosphorus (TP), total nitrogen (TN), hypolimentic volumetric oxygen depletion rate and phytoplankton species and biomass. TLI values provide a measure of the nutrient status of water bodies and are critical indicators of lake water quality. The following table

provides an indication of the lake types, trophic levels and values of the 4 key variables that define the boundaries for different trophic levels (from Burns et al. 2000).

Lake type	Trophic level	Chl a(mg m-3) (mg m-3)	Secchi depth (m)	TP (mg P m-3)	TN (mg N m-3)
Ultra-microtrophic	0.0 to 1.0	0.13 - 0.33	31 – 24	0.84 - 1.8	16 - 34
Microtrophic	1.0 to 2.0	0.33 - 0.82	24 - 15	1.8 - 4.1	34 - 73
Oligotrophic	2.0 to 3.0	0.82 - 2.0	15 - 7.8	4.1 - 9.0	73 -157
Mesotrophic	3.0 to 4.0	2.0 - 5.0	7.8 - 3.6	9.0 - 20	157 - 337
Eutrophic	4.0 to 5.0	5.0 - 12	3.6 - 1.6	20 - 43	337 - 725
Supertrophic	5.0 to 6.0	12.0 - 31.0	1.6 - 0.7	43 - 96	725 -1558
Hypertrophic	6.0 to 7.0	>31	<0.7	>96	>1558

Blue-green algae (BGA) levels[1] are also monitored by WRC in five shallow lakes (Lakes Hakanoa, Ngaroto, Waahi, Waikare and Whangape) to assess their suitability for contact recreation, whilst Hamilton City Council monitors BGA levels in Lake Rotoroa.

Lake water quality has also been monitored as part of WRC's shallow lake health indicators programme (see section 2.2). Under this programme, up to 17 lakes have been sampled three times per year (December, March and May). Six lakes have been monitored annually from 2006-2012 in this programme with a further 9-11 lakes selected (and varied) annually to extend data coverage, and/or complement other work programmes.

No water quality information has been collected by WRC for 50% of shallow lakes in the region.

2.1.1 Current condition

Table 1 summarises the nutrient enrichment status of 19 lakes that were monitored between 2006-2010 in WRC's water quality monitoring programme and in the shallow lake health indicators programme. More than half of these lakes (c. 63%), including all of the riverine and volcanic lakes monitored, had high levels of nutrient enrichment. All of the monitored dune lakes were found to be moderately enriched, whilst no karst lakes have been included in WRC's water quality monitoring programmes.

Nutrient enrichment levels range from moderate to extremely high in peat lakes, although standard and rotifer inferred trophic level indices may under-estimate the condition of dystrophic peat lakes that have higher humic content and lower algal concentrations than their nutrient (N and P) concentrations might otherwise suggest. Secchi depth readings in these lakes are also reduced due to factors other than primary production (Duggan 2012).

Table 1 **Trophic level index of 19 shallow lakes in the Waikato region in 2010, and 20 shallow lakes in the Waikato region in 2012[2].**
Lake types are indicated by colour in the following way: riverine, peat, volcanic, dune.

[1] Sample analysis involves algal counts of all taxa including BGAs, and BGA biovolume estimation
[2] As reported on WRC website Environmental indicators – http://www.waikatoregion.govt.nz/Environment/Environmental-information/Environmental-indicators/Freshwater/Lakes

Lake	Lake type	Trophic state (2006-10)		Trophic state (2008-12)	
		TLI (2006-10)	Nutrient enrichment	TLI (2008-12)	Nutrient enrichment
Harihari*	Dune	3.6	Moderate	3.8	Moderate
Otamatearoa*	Dune	4.0		4.0	
Rotomanuka	Peat	4.7		4.7	
Rotoroa (HCC data)	Peat	4.7		4.6	
Taharoa*	Dune	4.8		4.8	
Rotopiko North*	Peat	4.9		5.0	Very high
Rotopiko East	Peat	4.9		5.0	
Rotopiko South	Peat	5.2	Very high	5.2	
Maratoto	Peat	5.4		5.2	
Waahi	Riverine	5.9		5.8	
Tutaeinanga*	Volcanic	6.0		6.0	
Ngahewa*	Volcanic	5.9		6.1	Extremely high
Hakanoa	Riverine	6.0		6.1	
Mangakaware	Peat	NA	Extremely high	6.3	
Okowhao*	Riverine	6.2		6.3	
Ohinewai*	Riverine	6.3		6.3	
Milicich*	Peat	6.6		6.6	
Whangape	Riverine	6.9		6.8	
Waikare	Riverine	6.9		6.9	
Mangahia*	Peat	7.0		7.1	

2.1.2 Water quality trends

Water quality data has been analysed for trends by Barnes (2002a) and Vant (WRC) and are presented in Table 2. Water quality has improved in only two lakes (Lakes Whangape and Hakanoa) during the last 20 years, while water quality has shown periods of decline in Lakes Waikare, Rotomanuka and Waahi.

Table 2 Trends in nutrient enrichment for 9 shallow lakes between 1993 and 2012

Lake	Lake Type	1993-2001[1]	1995 - 2010[2]	2002-2010[2]	2005-2010[2]	1995-2012[2]	2002-2012[2]
Hakanoa	Riverine			Improved			Improved
Mangahia	Peat	No change					
Maratoto	Peat			No change			No change
Ngaroto	Peat	No change					

Rotokauri	Peat	No change					
Rotomanuka	Peat	Decline			No change	No change	
Rotoroa	Peat		No change			No change	
Rotopiko east	Peat			Declined			No change
Rotopiko north	Peat			No change			No change
Waahi	Riverine	No change	Declined			Declined	
Waikare	Riverine	Decline			No change	No change	
Whangape	Riverine	Improved		No change			No change

[1] From Barnes (2002a).
[2] Environmental Indicator data from WRC website (updated every 2 years)

Available water quality data is presented for each lake individually in later sections of this document.

2.2 Shallow lake health indicators

Lake water quality monitoring is not an effective or efficient way for WRC to measure and report upon the health of all lakes within the region over the long term, as water chemistry can change significantly over short periods of time, may not always reflect the ecological values and "health" of lakes, and requires regular and ongoing sampling. Furthermore, the costs associated with rigorous sampling of all of the lakes in the region are prohibitive.

To address these issues, WRC established a 'Shallow Lake Health Indicators Programme' in 2006 to investigate the development of biological and/or functional indicators of shallow lake ecosystem health (Neilson et al. 2008). The programme has involved assessment of a range of potential indicators of shallow lake condition, including invertebrates, zooplankton, aquatic plants, and wood decomposition. Water quality (see section 4.1), zooplankton and submerged macrophytes (Lake SPI) were subsequently selected as indicators of the ecological health of shallow lakes. Biological indicators are considered to be particularly important since they integrate a range of ecological factors and processes that are operating within the lake.

The following lakes have been visited and sampled (in December, March and May each year) as part of the Waikato Region Shallow Lake Monitoring Programme since its establishment in 2006. There have been overlaps between the two WRC programmes for 8 lakes (denoted by *) due to the different information collection requirements of each programme and frequency of visits.

Table 3 Lakes visited in the Shallow lake health indicator programme since its establishment in 2006

Lakes	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13
Kaituna (Lake B)	✓						
Koromatua	✓						
Rotokawau		✓					
Milicich			✓	✓			
Rotokotuku					✓		
Areare					✓		
Te Kapa						✓	
Okoroire						✓	
Tunawhakaheke (Lake E)						✓	
Whakatangi (Lake A)						✓	
Ngaroto						✓	✓
Mangakaware					✓	✓	✓
Kainui							✓
Maratoto*		✓	✓	✓			✓
Rotomanuka*		✓	✓	✓	✓		✓
Serpentine east*		✓	✓	✓	✓	✓	✓
Serpentine south		✓	✓	✓	✓	✓	✓
Serpentine north*	✓	✓	✓	✓	✓	✓	✓
Mangahia	✓	✓	✓	✓	✓	✓	✓
Parangi		✓					
Puketi					✓		
Otamatearoa	✓		✓	✓	✓		
Harihari	✓	✓	✓	✓	✓	✓	✓
Taharoa	✓	✓	✓	✓	✓	✓	✓
Tutaeinanga		✓	✓	✓			
Ngahewa		✓	✓	✓			
Kimihia	✓						
Okowhao		✓	✓	✓			
Hakanoa*					✓		✓
Penewaka					✓		
Ohinewai		✓	✓	✓	✓		✓
Waahi*	✓	✓	✓	✓	✓	✓	✓
Waikare*		✓	✓	✓	✓	✓	✓
Whangape*		✓	✓	✓		✓	✓

2.2.1 Zooplankton

Lake trophic state has been found to be a major determinant of rotifer (microscopic zooplankton) community composition and distribution in North Island lakes (Duggan et al. 2001a,b). On this basis, Waikato Regional Council has investigated the use of a rotifer community composition index (Rotifer Trophic Lake Index) as an indicator of lake trophic status. Whilst this method appears promising, rotifer species' distributions can be influenced by a range of other factors, including the presence of cyanobacteria, predatory zooplankton and oxygen depletion. As a result, rotifer TLI scores may not always reflect lake trophic status, and further investigation of this method is recommended (Duggan et al. 2001, Ozkundakci & Hamilton 2012).

Average rotifer inferred TLI scores for 15 Waikato lakes are shown in the table below (from Duggan 2014 *in prep*).

Table 4 Average rotifer-inferred TLI values from samples collected in December, February & March (Duggan 2014 in prep)

Lake	2012/13	2011/12	2010/11	2009/10	2008/09	2007/08
Maratoto	2.01		2.96	3.20	3.43	
Serpentine east	2.29	3.35	2.97	3.27	3.16	3.38
Serpentine south	3.12	3.58	3.84	4.18	3.73	3.76
Harihari	3.46	2.18	1.3	2.31	4.21	4.74
Serpentine north	3.55	3.34	3.56	4.07	3.84	5.10
Rotomanuka	4.49	4.23	4.64	4.14	5.32	
Waikare	4.56	4.78	5.88	5.44	5.89	6.79
Ohinewai	4.85	4.73	5.25	4.54	3.65	6.67
Ngaroto	4.88	5.9				
Kainui	4.89					
Hakanoa	4.94		5.57			
Mangahia	4.96	5.09	6.27	6.13	6.39	5.03
Mangakaware	5.82	4.95				
Whangape	6.76		7.44	6.56	7.66	
Waahi	7.00	7.12	6.47	6.78	6.41	7.88

2.2.2 Submerged aquatic plant indicators (Lake SPI)

Submerged plants are thought to be effective indicators of lake ecological condition as they are:

- easy to observe and identify and are commonly found in lakes all year round;
- mostly rooted to the bed of lakes, so are non-mobile;
- able to integrate long-term changes in environmental conditions - therefore providing a more stable measure of overall lake condition, rather than responding to seasonal or daily changes in water clarity and chemistry; and
- mostly associated with lake edges/margins (the littoral zone), where there is greatest public interaction and interest – e.g. for recreation.

Lake SPI uses submerged plants as indicators of lake condition. Lake SPI scores are calculated using information about the composition and condition of native plants and the depth to which they grow. Lake SPI also provides a direct measure of the impact by

alien invasive weeds that have invaded lakes over the past 150 years, often displacing native species (Clayton & Edwards 2006a &b).

Invasive plants often become dominant in lakes prior to vegetation collapse by forming dense mono-specific weed beds that exclude other species. Although invasive species are not favourable in terms of overall lake condition, Lake SPI recognises that the presence of any submerged plant species in a lake is preferable to none, as the plants act to mitigate many of the symptoms of eutrophication (e.g., absorb nutrients, maintain water clarity, stabilise the water column, compete with phytoplankton). Retention and or restoration of submerged plant communities, is therefore a high priority.

2.2.3 Current condition

In a recent Lake SPI report, Edwards et al. (2010) summarised available information about submerged plant communities of 52 Waikato lakes including 39 shallow lakes that had been surveyed between 2004 and 2010. The results are presented in Table 5.

In 2010 Lake Serpentine North was the only lake that supported vegetation similar to near pristine/original condition although it showed signs of stress when it was surveyed in 2010. Lake Serpentine North and Lake Rotopounamu were the only known remaining examples of Waikato lakes in an all-native vegetated state, although Lake Rotopounamu has not been surveyed since 2004 (Edwards et al. 2010).

Lakes Serpentine East and Rotoroa were the only shallow lakes classified as being in "high" condition, although this represented a disappointing decline for Lake Serpentine East (previously scored as "excellent") due to reduced native plant diversity and the establishment of an invasive bladderwort (*Utricularia gibba*) in the lake.

One volcanic lake (Lake Ngahewa), and all of the West Coast dune lakes supported vegetation, and scored "moderate" lake SPI indices, although they have been invaded by exotic macrophytes and may be vulnerable to vegetation collapse. Nationally, most lakes fall into this category (Edwards et al. 2010).

Between 2008-2010, plant abundance at Lakes Serpentine South, Mangakaware and Kainui declined below the threshold (10% cover) for generating a Lake SPI score. The most significant of these changes was the widespread loss of well-developed pondweed vegetation at Lake Serpentine South, which previously had a high Lakes 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'. Edwards et al. (2010) suggest that these lakes may be sensitive to management if they are right at the threshold between turbid and clear water states.
The remaining Waikato lakes have effectively proceeded to the next and, often final stage where de-vegetation has occurred or where the lakes support less vegetation than the (10% plant cover) threshold for Lake SPI assessment. All of the surveyed riverine lakes, a significant proportion of the peat lakes, and one volcanic lake (Tutaeinanga) fell into this category. Many of these lakes have become turbid and dominated by planktonic algae, with major impacts on other lake biota and lake use.

Table 5 Status of submerged plant communities in Waikato shallow lakes surveyed between 2004-2010 (from Edwards et al. 2010)

Lake	Last Survey Date	Lake Type	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)	Overall Condition
Serpentine North	09/04/2010	Peat	89	75	0	Excellent
Rotopounamu	19/11/2004	Volcanic	71	43	0	High
Serpentine East	09/04/2010	Peat	62	71	37	
Rotoroa (Hamilton)	08/05/2009	Peat	52	50	37	
Harihari	23/03/2009	Dune	45	59	65	Moderate
Taharoa	21/04/2010	Dune	35	49	77	
Otamatearoa	08/03/2010	Dune	31	56	81	
Ngahewa	04/03/2008	Volcanic	29	26	67	
Parkinson	20/04/2010	Dune	23	29	82	
Rotoiti	18/10/2004	Dune	23	25	84	
Parangi	20/03/2008	Dune	22	11	75	
Puketi	18/10/2004	Dune	21	18	85	
Areare	-	Peat	0	0	0	Non vegetated
Hakanoa	-	Riverine	0	0	0	
Hotoananga	22/04/2010	Peat	0	0	0	
Kainui (D)	22/04/2010	Peat	0	0	0	
Kaituna	01/02/2007	Peat	0	0	0	
Kimihia	-	Riverine	0	0	0	
Koromatua	01/02/2007	Peat	0	0	0	
Mangahia	01/02/2007	Peat	0	0	0	
Mangakaware	22/04/2010	Peat	0	0	0	
Maratoto	11/03/2009	Peat	0	0	0	
Milicich	09/03/2009	Peat	0	0	0	
Ngaroto	-	Peat	0	0	0	
Ohinewai	03/03/2008	Riverine	0	0	0	
Okowhao	09/03/2009	Riverine	0	0	0	
Pataka	21/06/2007	Peat	0	0	0	
Posa	21/06/2007	Peat	0	0	0	
Rotokauri	-	Peat	0	0	0	
Rotokawau	18/06/2007	Peat	0	0	0	
Rotomanuka	21/06/2007	Peat	0	0	0	
Rotongaro	24/05/2005	Riverine	0	0	0	
Rotongaroiti	24/05/2005	Riverine	0	0	0	
Ruatuna	21/06/2007	Peat	0	0	0	
Serpentine South	09/04/2010	Peat	0	0	0	
Tunawhakapeka (E)	18/06/2007	Peat	0	0	0	
Tutaeinanga	04/03/2008	Volcanic	0	0	0	
Waahi	20/04/2010	Riverine	0	0	0	
Waikare	03/03/2008	Riverine	0	0	0	
Whangape	15/02/2005	Riverine	0	0	0	

2.3 Restoration & management

Lake restoration and management projects are often undertaken to improve lake values (eg cultural, historic, recreation, wildlife, water quality) and uses (eg swimming, hunting, fishing, water source).

In the Waikato region, where shallow lakes are known to be amongst the most degraded nationally, the majority of shallow lake restoration projects have involved:

- establishing minimum lake levels;
- riparian retirement (including fencing);
- enhancement of marginal habitat, including re-vegetation and weed control;
- pest fish control;
- reduction of nutrient and sediment inputs; and
- improving access to the sites for recreation and management purposes;

The specific restoration and/or management activities that WRC have undertaken are summarised in detail for each lake and have usually been undertaken in conjunction with land-owners and/or other agencies.

2.3.1 Lake level setting

The hydrology of many of the lakes and wetlands in the Waikato region has been substantially modified as a result of drainage activities undertaken within their surrounding catchments for agricultural development. Lake outlets have been created and/or deepened to facilitate drainage, which has led to many lakes becoming much smaller and shallower than they would have been historically. Some lakes (e.g. Round Lake that was located east of the Serpentine/Rotopiko Lakes) have been completely drained and converted to pasture.

The Waikato Regional Plan (WRP) identifies minimum lake levels that have been established for 15 lakes in the region (standards in s.3.2.4.7). These levels are a combination of levels that were originally established under the Water and Soil Conservation Act 1967, whilst others have been established under the Resource Management Act 1991 and the Waikato Regional Plan. A further 15 peat lakes and wetlands are identified in section 3.7.4.5 of the Plan that require lake or bed level setting exercises. Waikato Regional Council is identified to undertake these processes, in conjunction with other agencies, and introduce them to the WRP through subsequent variations/changes.

The process to establish a minimum lake level involves:

- baseline water level monitoring in some circumstances;
- surveys of the lake outlet and surrounding land levels to enable inundation mapping and placement of water level control structures;
- determination of ecologically appropriate minimum summer water levels, in conjunction with affected parties;
- hydrological modelling of some systems to design an effective control structure to meet minimum summer lake levels;
- obtaining necessary resource consents;
- ongoing monitoring and maintenance to determine effectiveness of the structure

Water level monitoring is particularly valuable throughout this process as it provides a baseline for the pre-existing situation, and may also be used to calibrate and/or verify the hydrological models that are used to assist with the design of control structures.

Significant progress has been made in the Peat Lake Level Setting Programme outlined in the WRP (as summarised in Table 6) although further progress is required to set

minimum levels for Lakes Hotoananga, Henderson's Pond, Rotongata, Rotopotaka, and Maratoto. Waipa District Council manages Lake Ngaroto and is responsible for setting minimum lake levels at this site.

In sites where the installation of lake level control structures is likely to be problematic, it has been possible to identify and survey the heights of structures or other features (e.g. culverts or clay sills in outlets) that effectively set the current minimum lake levels. This information is shown in Table 5 for addition to the WRP in future. In addition to the progress listed in Table 5, WRC has also installed new weirs at Lakes Areare and Rotomanuka at the height standards set in s.3.2.4.7 to replace leaking or damaged structures to maintain minimum lake levels.

Table 6 Established minimum lake levels and progress on lake level setting for lakes identified in the Waikato Regional Plan

	Minimum lake levels set as standards in the WRP (s. 3.2.4.7)		**Lake level setting processes identified in section 3.7.4.5**	
	(Moturiki datum)		**Lakes that require processes**	**Progress**
Currently identified in the WRP	Waahi	7.80 m	Milicich	Surveyed
	Kimihia	8.00 m	Cameron/Kareaotahi	Surveyed
	Hakanoa	8.51 m	Serpentine/Rotopiko	New weir
	Rotokauri	22.50 m	Hotoananga	Still to do
	Whangape	4.91 m	Areare	New weir
	Mangakaware	29.10 m	Rotomanuka	New weir
	Mangahia	36.80 m	Whakatangi	New weir
	Komakorau	21.90 m	Henderson's Pond	Still to do
	Koromatua	39.13 m	Posa	Surveyed
	Kainui	24.81 m	Pataka	Surveyed
	Ruatuna	38.61 m	Rotongata	Still to do
	Maratoto	51.30 m	Pikopiko	New weir
	Areare	22.50 m	Rotopotaka	Still to do
	Cameron/Kareaotahi	48.50 m	Maratoto	Still to do
	Rotomanuka	50.10 m	Ngaroto (led by Waipa DC)	In progress
New lakes to be added to the WRP through a variation or plan change	Milicich 40.74m (sill) Whakatangi 26.84 (weir) Pikopiko 20.0m (weir) Ruatuna 38.75m (weir) Mangakaware 29.25m (weir) Tunawhakaheke/E 29.66m (weir) Serpentine/Rotopiko 54.92m (weir) Cameron/Kareaotahi 48.5m Posa 42.13m (culvert) Pataka 43.01m (outlet/sill) Ngaroto-iti 34.76m (culvert)		Mangahia Ruatuna	

Several other large, riverine lakes have water level regimes that are considerably lower than their historical minimums – including Lakes Rotongaro, Rotongaroiti, Whangape

and Waikare. The levels of these lakes have been altered in conjunction with the Lower Waikato Flood Control Scheme, and are described in more detail for each individual lake.

2.3.2 Riparian retirement and fencing

Riparian retirement, fencing and planting is an important aspect of lake restoration - particularly in pastoral catchments and is often the first step in lake restoration programmes. Riparian zones and wetland margins act as "buffer" zones between land and water, provide important habitat for native species, and serve to slow and filter runoff, thereby reducing nutrient and sediment loads entering the lakes from surrounding land.

Section 4.3.3 of the WRP describes WRC's policies for managing river and lake bed disturbances caused by physical modification, vegetation introduction and/or clearance, and livestock access to waterbodies. In addition to its use of non-regulatory methods[3] and rules for stock exclusion from waterbodies, Waikato Regional Council requires livestock to be excluded from mapped portions of Priority 1 water bodies that are identified in Table 4-1 of the WRP. A second set of waterbodies (Priority 2) were also identified for consideration at Plan review and for funding allocation during planning processes. The margins of the following lakes are identified in the Waikato Regional Plan:

Priority 1 - mapped as stock exclusion areas in the Regional Plan maps	**Priority 2**
Lakes Rotongaro & Rotongaroiti	Lake Ngaroto
Lake Okowhao	Matahura Catchment
Lake Whangape	Whangape Catchment
Lake Waikare	Waahi Catchment
Lake Serpentine	Lake Harihari
Lake Kuratau	
Lake Taharoa	
Lake Rotomanuka	
Lake Mangakaware	
Lake Ohinewai	
Lake Waahi	
Rotokawau	

Wetlands listed in Waikato Regional Plan (s. 3.7.7) are also identified as priority 1 waterbodies – including those associated with Lakes Whangape, Rotomanuka, Serpentine, Ngarotoiti, Rotokawau, Lake Waikare, Ngaroto, Areare, Hotoananga, Pikopiko, Kaituna (B), Lake Tunawhakaheke (E), Ruatuna, Ohinewai, Kopuera, Rotongaro, Okowhao, Cameron, Mangakaware, Maratoto, Mangahia, Kopuatai and Torehape.

Waikato Regional Council has worked with a number of landowners and other agencies to help exclude stock from Priority 1 stock exclusion lakes and wetlands. Financial assistance and advice has been provided to fence, plant, and extend riparian margins at priority lakes.

Table 7 summarises the current state of fencing in shallow lakes. Whilst stock exclusion is the minimum requirement of the WRP, permanent 5 wire fencing (with 2 electric), and

[3] including education and incentives

7 wire post and batten are becoming the minimum acceptable fencing standards for excluding cattle and sheep, respectively.

Table 7 **Current extent of fencing in shallow lakes in the Waikato region**
Lakes in italics indicate lakes where there is some uncertainty over extent of fencing. Lakes with a * indicate priority 1 stock exclusion lakes (identified in the WRP). Lake types are indicated by colour in the following way: riverine, peat, volcanic, dune, karst, unknown.

No fencing required	100% fenced	> 50% fenced	< 50% fenced	No fencing	Not known
Rotoroa (Hamilton)	Kaituna*	Kopuera*	*Waitamoumou**	Otamatearoa	Taharoa*
Hakanoa	Komakorau*	Rotokawau*	Whakatangi		Disappear
Kopuatai Burn Pools	Mangahia*	Rotongaro*	Pikopiko*		Numiti
Koraha	Mangakaware*	Waikare*	*Te Otamanui*		Parkinsons
Rotokaeo	Maratoto*	Whangape*	Harihari		Piopio
Rotopounamu	Ngaroto*	Kimihia	Henderson's Pond		Puketi
Te Koutu	Ngarotoiti*	Posa	*Rotopotaka*		Rotoiti
Unnamed 9 (Lake Opuatia)	Ohinewai*	Rotongata			Rotokaraka
Waiwhakareke	Okowhao*				Rotoroa (Kawhia)
	Penewaka*				Rototapu
	Rotomanuka*				Te Kapa
	Rotongaroiti*				Te Rotopupu
	Serpentine/ Rotopiko*				Unnamed 3
	Ruatuna*				Waiwhata
	Waahi*				
	Areare				
	Cameron				
	Kainui				
	Koromatua				
	Leesons Pond				
	Milicich				
	Ngahewa				
	Okoroire				
	Pataka				
	Patetonga				
	Rotokauri				
	Rotokotuku				
	Tunawhakapeka				
	Tutaeinanga				
	Parangi				
	Hotoananga*				

Considerable progress has been made in riparian fencing with 63% of Priority One lakes fully fenced. Overall 56% of shallow lakes currently exclude stock or do not require fencing, however some of these existing fences do not reflect the true legal boundary (eg Lakes Whangape, Rotongaro, Rotongaroiti, Ruatuna and Tutaeinanga) and considerable benefits could arise if these fences were realigned.

2.3.3 Enhancement of marginal habitat

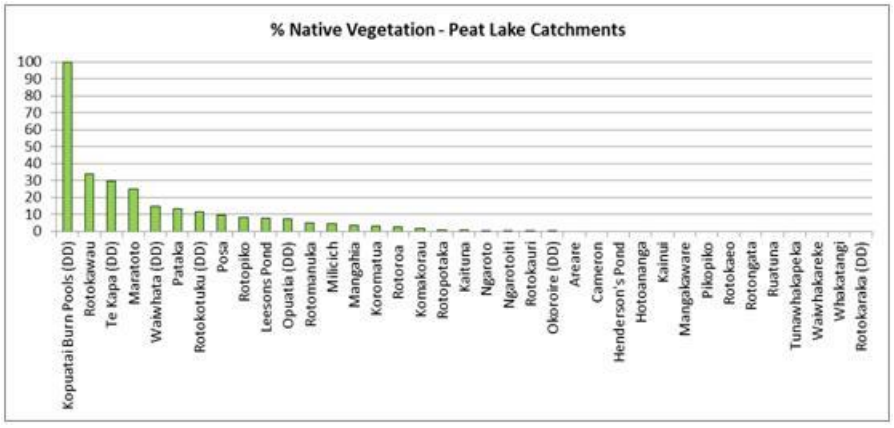
Most shallow lakes are situated within pastoral catchments with narrow riparian margins, and small adjoining wetlands. The continued existence of these areas has largely depended on their reservation and maintenance as public reserve land. Historically, these areas would have been far more substantial, and would have provided important habitat for terrestrial and aquatic species and wildlife. As well as their biodiversity value, these areas would also have played a critical role in maintaining water levels (and reducing flood peaks), and filtering contaminants from runoff and groundwater. It is therefore a high priority to protect and/or restore lake margins, associated wetlands and other native vegetation within the catchments of shallow lakes.

The only shallow lakes that still have largely forested catchments are Lake Rotopounamu which is situated within a conservation area, and the Kopuatai Burn Pools that are associated with the Kopuatai peat dome (Figure 3). Lake Koraha also has greater than 50% of its catchment in native forest, and is located within a conservation area. The Taharoa dune lakes (Lakes Numiti, Rotoroa, and Taharoa) have retained at least 30% native vegetation within their catchments, and WRC has made initial approaches to the Taharoa Lakes Trustees to assess the condition of the lakes and identify future management options to safeguard them.

Most other lakes have 0-20% native vegetation within their catchments, and it is common for lakes in the lower Waikato to have less than 5% native vegetation in their catchments.

WRC has also assisted private landowners to prepare and/or implement restoration plans for privately owned wetlands and lake margins that adjoin Lakes Maratoto, Mangahia, Rotokotuku, and Okoroire. Substantial wetland restoration projects have also been undertaken at Lake Kaituna, Lake Rotomanuka, the Serpentine/Rotopiko lakes, and Lake Mangakaware where WRC has contributed to multi agency work programmes. Restoration options have also been assessed for some of the larger riverine lakes, including Lakes Whangape, Rotongaro, Rotongaroiti, Waikare and Kimihia. Other agencies and care groups have also undertaken substantial lake margin restoration of at Lakes Komakorau, Koromatua, Hotoananga and Ohinewai.

Hamilton City Council are undertaking a substantial and ambitious restoration programme within the catchment of Lake Waiwhakareke that involves a substantial revegetation programme to re-create permanent native forest on 50 ha (76%) of the lake's catchment. It is thought that water quality could improve in the next 10-20 years to a moderate (meso-trophic) trophic state as a result (Duggan 2012).



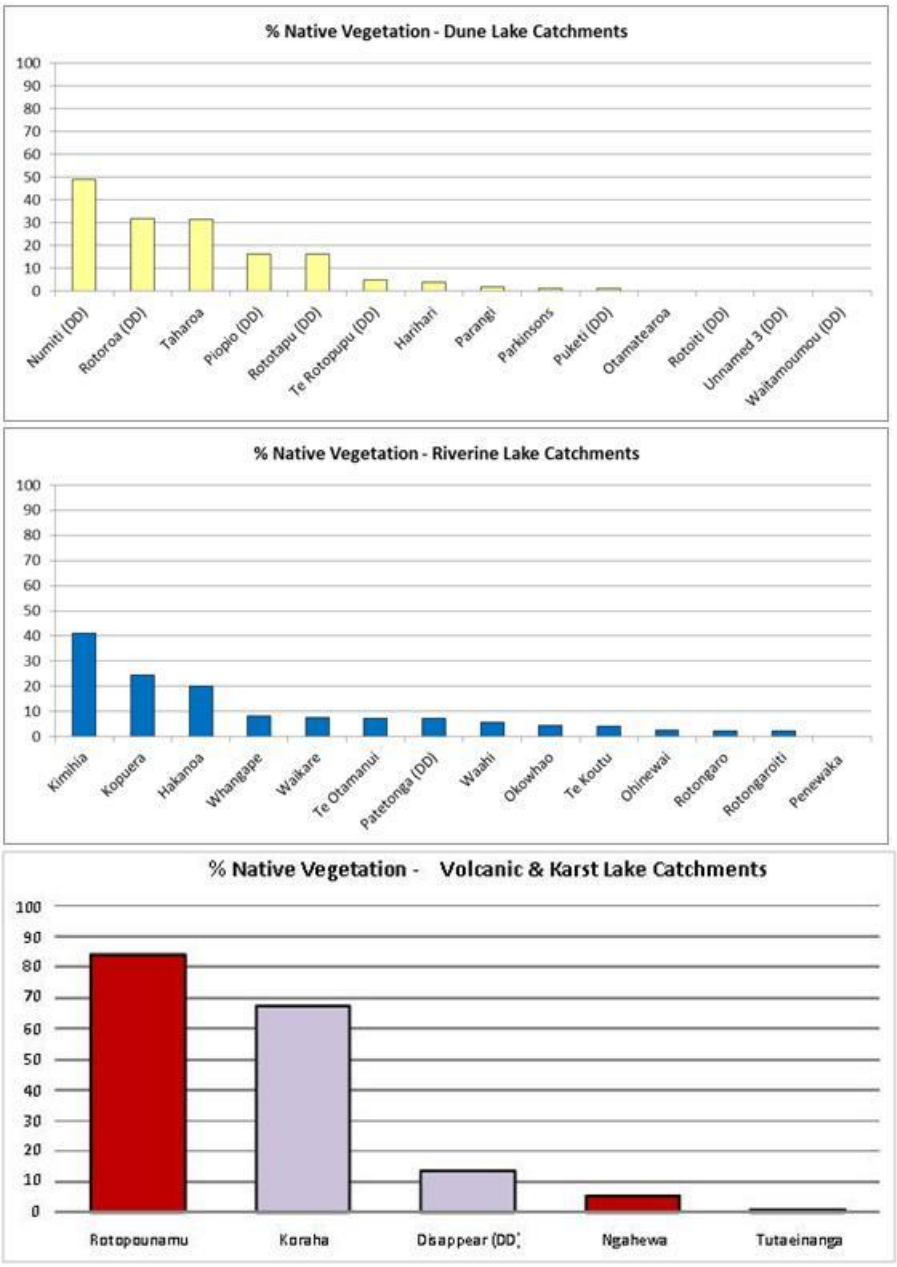


Figure 3 Estimated native vegetation cover in the catchments of shallow lakes (by type) in the Waikato region
Lake types are indicated by colour in the following way: volcanic, karst.

2.3.4 Pest fish control

The Waikato region contains a number of introduced freshwater fish species including koi carp, catfish, goldfish, rudd, tench, perch, trout and *Gambusia.* Dense, problematic populations of these species have formed in some rivers and lakes. As a result, koi carp, goldfish, catfish and *Gambusia* are identified pests in the Waikato Regional Pest Management Strategy (RPMS). Perch, rudd and tench are also identified in the Waikato RPMS, although they are freshwater sports fish as defined by the Freshwater Fisheries Regulations 1983. Nevertheless, the RPMS provides for their eradication if necessary, in conjunction with Fish and Game New Zealand and the Department of Conservation.

Introduced fish can rapidly form dense populations and are thought to contribute to the deterioration of shallow lakes by:

- increasing nutrient levels and algal concentrations;

- contributing to erosion;
- feeding on and removing native aquatic plants;
- preying on invertebrates, native fish and their eggs; and/or
- competing with native species for food and space.

These effects mostly arise from their benthic foraging and feeding activities, macrophyte removal, or by increased nutrient recycling as benthic feeding fish excrete significantly more phosphorus than other fish (Rowe 2004). Koi carp and brown bullhead catfish are also known to assimilate substantial amounts of nutrients into their flesh (B. David *pers. comm).*

Sondegaard et al. (2007) reported increased water clarity and reduced algal density associated with the removal of zooplanktivorous and benthivorous fish in a review of 70 lake restoration projects in shallow, eutrophic European lakes. Maximum effectiveness of the projects was observed 4-6 years after fish removal, and was only maintained by repeated fish removal. Insufficient reductions of external nutrient load, internal phosphorus loading (via sediment resuspension) and loss of stable submerged macrophyte communities were identified as the most likely reasons for lakes reverting to their original (i.e. poorer) condition prior to fish removal.

Overseas, pest fish control /removal is seen as an important restoration tool to establish clear water conditions in shallow lakes that promote submerged plant growth, and to reduce nutrients and suspended solids (Sondergaard et al. 2007). Some authors suggest that establishment of a dense and stable cover of submerged macrophytes may be a prerequisite for long term restoration and rehabilitation of shallow lakes.

Introduced benthic feeders (e.g. koi carp (*Cyprinus carpio*), goldfish (*Carassius auratus*), rudd (*Scardinius erythrophthalmus*) and brown bullhead catfish (*Ameiurus nebulosus*) are widespread in Waikato lakes to the extent that they are likely to be affecting water quality and submerged macrophytes. The biomass of introduced fish in the Waikato River between Ngaruawahia and Tuakau has been estimated to be 89% of the total (Hicks et al. 2010) which was comprised of koi carp *Cyprinus carpio* (82.6%), goldfish *Carassius auratus* (5.8%), rudd *Scardinius erythrophthalmus* (0.8%) and brown bullhead catfish *Ameiurus nebulosus* (0.7%).

To date, projects involving pest fish control have been attempted at the following 4 shallow lakes:

- **Lake Rotoroa (Hamilton)** is the only shallow lake in the region that has undergone a shift back from a turbid/devegetated state back to supporting macrophytes and improved water quality. Charophytes were reintroduced and caged to protect them from browsing by pest fish (particularly rudd).

- **Serpentine/Rotopiko Lakes** - This lake complex has the best remaining native submerged plant communities in the Waikato region, but these plants are vulnerable to the feeding and foraging behaviours of rudd and brown bullhead catfish. A research experiment was undertaken by DOC and WRC to test netting techniques for rudd control and/or eradication (Neilson et al. 2004). DOC has maintained an ongoing pest fish control programme, since the conclusion of the research programme, while investigating long-term eradication options. A pest fish barrier has also been constructed in the drain downstream of the lake complex.

- **Lake Ohinewai –** Waikato University (with funding from DOC) are testing the use of a one-way pest fish gate on the outlet of Lake Ohinewai to capitalise on the seasonal migratory movements of koi carp within the lower Waikato River

system. The gate provides for fish to exit the lake and prevents large koi from re-entering the lake.

- **Lake Waikare –** An invasive fish trap/cage has been installed on the fish pass at the outlet of Lake Waikare to capture and remove invasive fish species that migrate into Lake Waikare from the Waikato River. Fish are trapped in the cage and minced flesh is digested in a low energy protein digestion process to produce a dry product that is suitable for a range of uses, including plant fertiliser. The commercial potential of this system is currently being evaluated. It is envisaged that this type of technology could be applied at various sites within the lower Waikato River system to coincide with dispersal and seasonal migration events.

Several of these programmes have been undertaken in conjunction with the University of Waikato's Pest Fish (FRST-OBI) Research Programme. Recently a collective has been formed[4] to investigate management options for pest fish control in the Waikato River system, and to advise on future management options and opportunities.

2.3.5 Reduction of nutrient and sediment inputs

Reducing external nutrient and sediment inputs to water bodies is a key focus, since many of the lakes receive large nutrient and sediment loads arising from intensive use of their surrounding catchments.

The most commonly used methods to manage point source (ie direct discharges) or diffuse pollution have involved wetland construction/enhancement, riparian planting, stock exclusion (via fencing) and the installation of silt traps. WRC has relied primarily on non-regulatory methods (education and incentives) to date and has offered financial subsidies for landowners to fence and plant riparian areas through the Clean Streams and Catchment New Works Programmes, and through external funding.

WRC have also supported the testing and development of constructed wetlands and silt traps to reduce sediment and nutrient inflows to peat lakes. Recent studies have focused on the design of these structures to maximise nutrient and sediment removals, with a view to developing best practice guidelines for application at other shallow lakes within the regions. To date silt traps have been constructed on inflows at Lakes Kaituna, Komakorau and Kainui, with traps also proposed for Lakes Mangakaware, Areare, Serpentine/Rotopiko, Rotomanuka and Ruatuna. The use of floating wetlands to increase nutrient uptake within the silt traps is also being studied at Lake Kaituna.

Whole farm system planning is a relatively new approach to working with landowners within the catchments of shallow lakes to encourage them to reduce the impacts of their land use on the lakes. Various agencies have provided funding for farm system plans (including nutrient budgets) to be prepared for landowners within the catchments of Lakes Kaituna, Tunawhakaheke, Mangakaware, Serpentine/Rotopiko, Ngaroto and Rotomanuka to identify options to reduce nutrient and sediment losses from their properties. To date, the main recommendations have involved:

- more efficient application, monitoring and management of fertiliser and effluent (with a focus on reducing phosphorus and nitrogen losses to waterways);
- improved stock management to improve overall production;
- improved peat soil management practices;
- improved drain and water way management; and
- improved management of lake margins.

[4] Involving representatives from WRC, DOC, Waikato-Tainui and Waikato University

Initial results suggest that there is considerable scope for landowners to reduce their nutrient and sediment losses, and improve animal health whilst maintaining their present levels of profitability.

In parallel to the farm planning processes on properties within the catchments of Lakes Mangakaware and Serpentine, a monitoring programme has also been initiated to assess nutrient and sediment loads entering the lakes from inflowing drains, with a view to quantifying the extent to which nutrients and sediment losses from the adjacent farmland are reduced through farm system changes (arising from farm plans). This baseline information, coupled with greater knowledge about the effectiveness of constructed wetlands, silt traps and other nutrient mitigation methods should assist WRC to determine whether it is possible to reduce external nutrient and sediment loads to these lakes by 50% - the level of reduction that Faithfull et al. (2006) recommended before any consideration of internal nutrient removal would be warranted for sensitive peat lakes within the Waikato region. The information could also be used to assess and model future restoration scenarios for these priority lakes.

2.3.6 Access to lakes

Physical access to shallow lakes is essential for their management and monitoring, and is a key aspect of shallow lake management and restoration projects.

In recent years, Waipa District Council has made a concerted effort to acquire esplanade reserves and additional margins around peat lakes in order to create and plant wider riparian margins to reduce catchment inputs, and secure or improve public access to these lakes. To date, 27.9 ha of esplanade reserve have been added to peat lakes in the Waipa District since 2009 (Paula Reeves, Waipa District Council, *pers. comm.*). These efforts go some way towards progressing the recommendations of Thompson & Champion (1993) regarding esplanade reserves for Lakes Serpentine, Mangahia, Rotomanuka, Ruatuna and Cameron.

In Appendix G of its District Plan, Waikato District Council has identified Esplanade Priority Areas where it wishes to secure public access (as part of subdivision processes) to and along waterbodies and to the coast, including:

- road access esplanade reserves and/or pedestrian access for Horsham Downs lakes (Lakes Hotoananga, Pikopiko, Areare, Kainui, Whakatangi (A), Kaituna (B), Komakorau (C), Tunawhakaheke (E);
- vehicle access to Lakes Rotokawau and Kimihia over specified properties; and
- access to boat ramp sites at Lakes Waikare, Whangape, Rotongaro, Rotongaroiti and Okowhao over specified properties.

Waikato Regional Council's role in relation to public access is primarily one of advocacy and promotion. The regional council seeks to encourage and support other agencies to secure public lake access through their district plan processes or other mechanisms where applicable and appropriate.

In 2007, Kelly & Di Pierro (in draft) assessed the potential public accessibility of lake margins in the region for lakes greater than 2ha in surface area. They estimated that 42% of the total length of lake perimeter (c. 836,000m) abutted publically accessible land parcels, whilst 58% adjoined private land. Table 7 provides the estimated proportions of publicly available lake margin within each territorial authority in 2007.

It should be noted however that this analysis did not take into account the practical accessibility of the public land adjoining many of the lakes, so may over-estimate the extent of public access to them. In many instances, the margins of lakes are held by the Crown but do not have a formed accessway from the nearest public road. As a result they are not publicly accessible.

Good public access to (publicly owned) lakes is an important precursor for lake management, conservation, and public recreation. At Lake Areare, DOC and Waikato District Council have worked together in the management of road, esplanade and wildlife management reserves to facilitate public access to the lake. This in turn has facilitated significant lake restoration, monitoring and enhancement works, as well as access for recreational users.

Table 8 Estimated length and total percentage of lake margin that was potentially accessible to the public in territorial authorities in the Waikato region in 2007 (from Kelly & Di Pierro in draft)

Territorial authority	Total length of lake margin (m)	Length of publicly accessible lake margin (m)	% Lake margin publicly accessible
Hamilton city	6,056	6,056	100.0%
Hauraki district	1,602	1,602	100.0%
Waikato district	172,209	130,612	75.8%
Taupo district	292,905	131,405	44.9%
Rotorua district	93,306	30,891	33.1%
Waipa district	106,516	31,774	29.8%
Franklin district	4,277	1,042	24.4%
South Waikato district	116,731	16,734	14.3%
Otorohanga district	17,500	1,768	10.1%
Matamata Piako district	4,715	279	5.9%
Waitomo district	20,056	954	4.8%
Thames Coromandel district	0	n/a	n/a

3 Waikato peat lakes

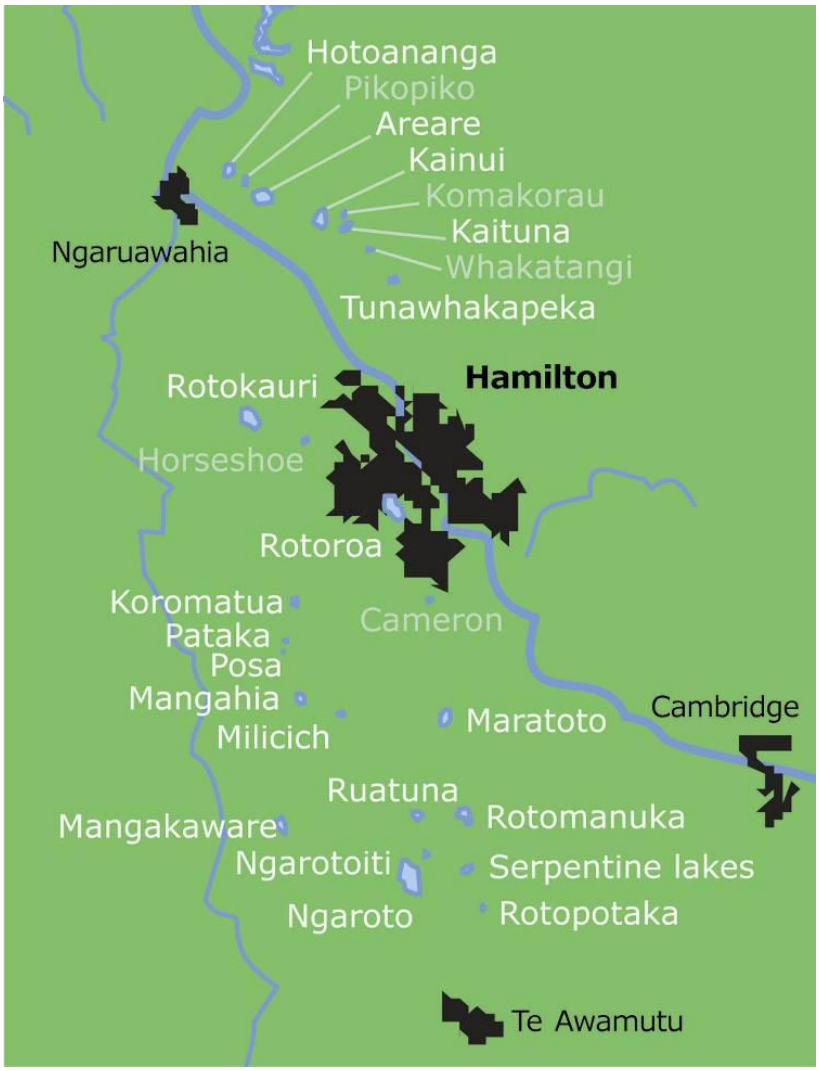


Figure 4 Peat lakes in the Waikato region

The Waikato peat lakes are concentrated in the Waikato and Waipa Districts and represent the largest collection of this wetland type in New Zealand. The lakes formed in the historic floodplain of the Waikato River, where sand and gravel from the Waikato River blocked valleys at the time when the river changed course.

There are 37 peat lakes in the Waikato region. They are mostly small to moderate in size (1-33 ha). Lakes Ngaroto (108 ha), Rotoroa (55 ha) and Rotokauri (42 ha) are the largest of the peat lakes. Approximately 50% of peat lakes have catchment sizes less than 200 ha. All peat lakes in the Waikato region are located within predominantly pastoral catchments and few have extensive marginal wetlands remaining. Lake Maratoto has the largest area of adjoining wetland (22 ha).

These peat lakes represent some of the few remaining wetland areas associated with the formerly extensive Komakorau, Rukuhia and Moanatuatua peat bogs. In their natural state, they have unique characteristics that reflect this association including having naturally acidic water that is low in nutrients and dissolved oxygen, and is highly coloured or tannin-stained. As a result, the lakes provide critical habitat for a number of highly specialised, and often rare and threatened, plant and animal species.

Before European settlement, most of the peat lakes had no inlets or outlets. Water entered the lakes by subsurface flow from adjacent peat bogs and from rainfall, and was lost primarily through evaporation. Drainage of the surrounding peat bogs has lowered water tables, and subsequent farming activities have resulted in substantial peat shrinkage. As a result of reduced lake levels and the loss of their adjoining wetlands to filter nutrients and sediments from surrounding land, many of the lakes have become nutrient enriched

Almost 20% of peat lakes have insufficient information[5] to rank them for biodiversity management (Wildland Consultants Ltd 2011). Figure 5 shows scores (including best estimates) for different aspects of the lake biodiversity ranking process for peat lakes.

A very small number of peat lakes have high ecological significance scores. These lakes still retain submerged plants and/or have moderately sized wetland margins that retain a high degree of indigenousness.

The majority of peat lakes have similar ecosystem condition scores (of 15-20) that reflect their poor water quality, the presence of pest fish, the small size of their wetland margins and the extent of hydrological modification that has arisen from changes to catchment land use (ie drainage).

The most vulnerable peat lakes (Milicich, Pataka and Posa) are small lakes where land intensification has occurred or is likely to occur as a result of further drainage. These lakes are not thought to contain the pest fish, koi carp.

[5] Data deficient (DD) lakes are categorised as those lakes with more than 5 criteria that had to be estimated or couldn't be scored (Wildland Consultants 2011).

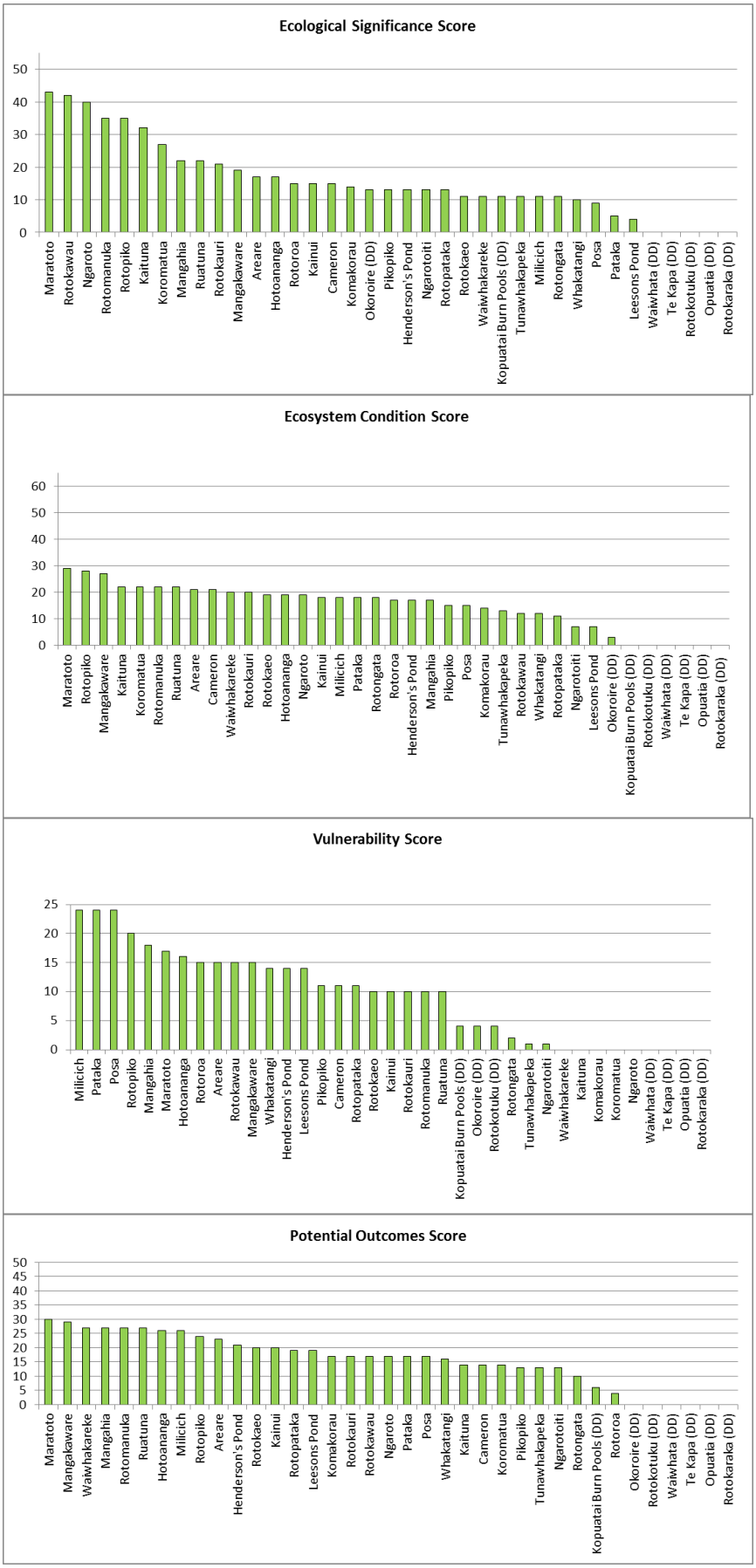


Figure 5 Peat lake scores (including best estimates) for different aspects of the lake prioritisation method used to rank lakes in the Waikato region

3.1 Hamilton city

3.1.1 Lake Rotokaeo (Forest Lake)

Depth	Unknown (1.8m)
TA	Hamilton City Council
WRC zone	Central Waikato
Land tenure	Recreation reserve administered by HCC
Lake area	3.1 ha
Estimated catchment area	Unknown
Catchment land use	Urban
Percent native vegetation cover in catchment	0
Applicable joint agency accord/MOA	None
Lake level in WRP	No
Identified as significant wetland (WRP Rule 3.7.7)	No
Identified as Priority 1 stock exclusion	No

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (3)	Lake type (36)	WRC zone (7)
34	1	20	4
Figures in brackets indicate the total number of lakes included in assessment.			

Waikato Regional Council does not hold any water quality data for Lake Rotokaeo, and Lake SPI assessments have not been undertaken at this site. Waikato University visited the lake in 2008 and recorded a SD of 0.55 m (Hicks et al, 2009). They described the water to be tannin stained without obvious suspended sediment.

Stormwater enters the lake via four stormwater pipes. Two of the inflows discharge into a wetland fringe that is likely to remove some of the contaminants, whilst the remaining inflows discharge directly into the lake (Dugdale and Reeves 2002).

Stock does not have access to the lake due to its urban location. There is a vegetated margin along the north-western and western lake edge ranging from 30-70 m wide. Hamilton City Council has carried out extensive weed control in the margin removing most of the grey willow and yellow flag and replanting with indigenous plants. The vegetated margin is now dominated by a diverse range of indigenous species and habitat types, including a young planted kahikatea forest. Other restoration work at the lake has included the almost complete removal of Mexican water lily (*Nymphaea mexicana*) which once dominated 85% of the lake surface (Dugdale and Reeves 2002).

The University of Waikato undertook an electric fishing survey of the lake in 2009 and found the native shortfin eel, and 3 introduced fish species - goldfish, G*ambusia* and brown bullhead catfish (Hicks et al, 2009). They suggest that the main threats include the introduction of further exotic fish species and ongoing stormwater inputs. Upstream migration of exotic fish (particularly koi carp which are not thought to occur in the lake) is thought to be unlikely due to a structure located at the outlet (Hicks et al, 2009), however illegal introduction could occur.

Options for management and acquisition of information:

- review options for including Lake Rotokaeo in WRC's Shallow Lake Health Indicator programme.
- advocate to Hamilton City Council for improved stormwater management to reduce impacts upon the lake.

3.1.2 Lake Rotoroa (Hamilton Lake)

Depth	6m
TA	Hamilton City Council
WRC zone	Central
Land tenure	Recreation reserve and wildlife reserve administered by City Council
Lake area	55 ha
Estimated catchment area	258 ha
Catchment land use	Urban
Percent native vegetation cover in catchment	2.56 %
Applicable joint agency accord/MOA	✕
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 Stock Exclusion	✕

Lake biodiversity ranking results (Wildland Consultants 2011)

Regional (71)	District (3)	Lake type (36)	WRC zone (7)
41	3	26	6
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Rotoroa is situated in central Hamilton, and is the focus of land and water-based recreational activities. The lake was associated with a former peat swamp that was initially drained for farming purposes and then developed for urban and residential use.

Catchment land use changes have significantly increased the volume and rate of water inflows and nutrient concentrations reaching the lake. Today, the lake receives water from stormwater drains, direct rainfall, and overland flow. Water is lost through evaporation and discharge via a (constructed) piped outlet that flows into the Waitawhiriwhiri Stream and eventually to the Waikato River. Groundwater is thought to make a small contribution to water inflows and outflows, and the hydrology of Lake Rotoroa is now almost entirely artificial (Hamilton City Council, 2009).

The water clarity of Lake Rotoroa has fluctuated significantly in the past, which has been attributed to cyclical changes in phytoplankton abundance (Tanner et al. 1987). Secchi depth measurements of 1.0 – 5.7m were recorded from the lake during 1978-1987, but water clarity declined between 1987 and 1991 which coincided with the collapse of submerged aquatic plants in 1989/90 (Tanner et al. 1987, de Winton et al. 2010). Three main water quality phases were observed thereafter. Between 1992-1998, water quality

improved rapidly from a supertrophic to eutrophic state, until 1999-2000 when improvement slowed and then stabilised (2001-2009). Analysis of TLI scores between 2000-2010 confirm that the lake's condition has been consistently eutrophic over this period (de Winton et al. 2010a).

Significant changes in SD and chlorophyll a concentrations occurred between 2000 and 2010 that were consistent with improved lake condition. However, a corresponding decline in phosphorus (the limiting nutrient in Lake Rotoroa) did not occur during this period (de Winton et al. 2010). Hamilton et al (2010) assessed water quality monitoring results during 2003-07 and concluded that concentrations of phosphorus, nitrogen, chlorophyll *a*, and water clarity had returned to similar levels as those recorded in the early 1980s (Hamilton et al. 2010). Recent water quality analyses of 2006-2010 water quality data indicate that the trophic status of Lake Rotoroa has been stable during this period (WRC; 2012). Results are presented in the table below.

	Mean SD (m)	**Mean Chl *a* ($mg\ m^{-3}$)**	**Mean TN ($mg\ m^{-3}$)**	**Mean TP ($mg\ m^{-3}$)**	**Estimated TLI**	**pH**	**Turbidity (NTU)**
1978-1980[a]	3.80						
1981[b]		9.5	719	25		6.7-7.5	2.6
1981-1984[a]	1.80						
1990-1991[c]	0.58-1.56						
1992[d]	0.84	27.4	1215	34.3	5.50		
1997[d]	1.31	9.4	685	26.1	4.60		
2002[d]	1.83	14.9	579	19.6	4.68		
2003-2007[e]	1.8	13	910	22			
2005/2006 [g]	1.85	11.8	820	19.7	4.73		
2006-2010[f]					4.7		
2007/2008[g]	1.98	13.5	831	15.4	4.57		
2009/2010[g]	2.11	7.5	618	20.3	4.48		

[a] Tanner et al. (1987)

b Davenport (1981); WVA based on 10 samples taken between January and March 1981

[c] de Winton et al. (1991)

[d] Waikato Regional Council analysis (Jan 1992-Dec 2002)

e 2003-2007 Waikato Regional Council data reported in Hamilton et al (2009)

f 2006-2010 Waikato Regional Council – Shallow lakes water quality monitoring programme – monthly samples. Data taken from Nutrient enrichment of shallow lakes State of the Environment Indicator: WRC (2012)

g de Winton et al. (2010)

Lake Rotoroa has a well documented history of weed invasion that have seen the lake dominated by exotic weed species, completely devegetated, and then re-colonised by native charophytes. It is one of a few shallow lakes in New Zealand that have transitioned from a devegetated, algal-dominated state to a clear water, macrophyte-dominated state, so has been of scientific interest and has been subject to regular monitoring for Hamilton City Council.

In 2010, Lake Rotoroa was one of only four lakes surveyed by NIWA that had a "high" Lake SPI score, although the score was lower than previous survey scores due to the re-

appearance of *Egeria densa* in November 2002 (Edwards et al. 2010). *Egeria* beds are being carefully monitored with spot control occurring as necessary to maintain lake access and use (de Winton et al. 2010).

The lake has a long weed management history and chemical control has been undertaken repeatedly since the oxygen weed *Lagarosiphon major* was first recorded from the lake in the 1950's. In 1959, sodium arsenite was aerially applied to Lake Rotoroa to control aquatic weeds. While this treatment effectively eliminated submerged aquatic plants for 5 years, elevated levels of arsenic persist in the lake sediments today (HCC 2009, Champion et al. 1993, Tanner & Clayton 1990). Diquat has been applied to the lake many times since 1971 – initially to control *Lagarosiphon major* and *Elodea canadensis*, and later to control mostly *Egeria densa* that had become established in the lake. Initial treatments involved aerial spraying of the entire lake area, but applications later became more selective with the development of gel diquat formulations (Tanner 1990, Champion et al. 1993).

By 1991, submerged plant species had been completely removed from the lake through multiple herbicide treatments, and the lake remained de-vegetated for several years. The removal of the oxygen weeds allowed native charophytes to regenerate, and by late 2005 these species occupied most available habitat within the lake (Hamilton City Council 2009). A substantial charophyte die back was observed in 2007 that was attributed to pest fish[6], although the plants subsequently recovered. A further, die-back was detected in 2010 that reduced charophyte density below 2007 levels, which may have been due to wind/wave disturbance during drought periods, grazing pressure from fish or birds, and/or competition with filamentous algae (de Winton et al. 2010). A shift in species dominance from *Chara australis* to *Nitella* aff. *cristata* also occurred during this period, which may have altered the susceptibility of charophytes to adverse impacts.

Similar switches have been observed for phytoplankton. The lake has been dominated by dinoflagellates since 2005, although significant populations of blue-green algae emerged for the first time on record during the summer of 2009/2010 that exceeded recreational contact standards. De Winton et al. (2010) suggest that this may have been the result of a combination of physical and chemical conditions[7] that occurred during February/March 2010. Since then, Hamilton City Council commissioned a feasibility study to assess sediment capping and other algal control options (NIWA 2011).

Considerable effort has been undertaken by Hamilton City Council to eradicate weeds in marginal plant communities. Grey willow (*Salix cinerea*), crack willow (*Salix fragilis*), yellow flag, water lilies (*Nymphaea* spp.) and pampas (*Cortaderia* sp.) have been greatly reduced. Of note is the removal of over 1.7 ha of yellow flag, a weed that was introduced into the lake in the 1940's and is possibly the source of yellow flag infestations in the lower Waikato basin. Re-vegetation with indigenous species within the marginal fringe now complements the large beds of indigenous emergent macrophytes.

The lake level is managed by Hamilton City Council to an agreed height of 37.15m (Moturiki datum). Council staff monitor lake levels using a gauge at the outlet of the lake, and adjust the height of the outlet weir manually by adding or removing timber boards. HCC have indicated their intention to design and install an improved weir structure in future to improve the ease and accuracy of water level management (Hamilton City Council, 2009).

Lake Rotoroa is dominated by exotic fish species including perch, rudd, brown bullhead catfish, tench, goldfish and *Gambusia*. Whilst the coarse fishery is valued, there are

[6] as it occurred in the shallow water zone which is less affected by reduced water clarity.
[7] Warm, stable weather with little wind that would have reduced water mixing and led to sediment anoxia, resulting in the release of soluble nutrients for cyano-bacterial growth

ecological concerns about the presence of some of these fish species (Hamilton City Council 2009). Native eels and common bullies also occur in the lake, and freshwater mussels were re-introduced to the lake in 2001 in an attempt to re-establish a naturally reproducing population for water quality purposes. Common smelt historically occurred at the lake but are no longer present.

Options for management and acquisition of information:

- contribute to the implementation of the management plan for the Hamilton Lake Domain for activities which fall within WRC's mandate (led by Hamilton City Council)
- provide ongoing technical and water quality support and assistance to HCC to support its management of Lake Rotoroa.

3.1.3 Lake Waiwhakareke (Horseshoe Lake)

Depth	2-3m
TA	Hamilton City Council
WRC zone	Central Waikato
Land tenure	Hamilton City Council corporation land (no reserve status)
Lake area	3 ha
Estimated catchment area	c.66ha
Catchment land use	Retired dairy & drystock/urban
Percent native vegetation cover in catchment	0
Applicable joint agency accord/MOA	✕
Lake level in WRP	Level controlled by Lake Rotokauri
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (3)	Lake type (36)	WRC zone (7)
35	2	21	5
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Waiwhakareke is a peat lake that formed on the margin of the Te Rapa peat bog. The lake is situated within a 60 ha site that is known as the Waiwhakareke Natural Heritage Park (WNHP), and will be the central feature of the park. The land was purchased by Hamilton City Council in 1975 and was leased for farming, but is now subject to a retirement and ecological restoration programme that involves planting, and pest control of the area - including the lake and its wetland margins (Hamilton City Council 2010).

The lake's catchment is mostly agricultural, although one portion has been urbanised. Revegetation is underway on the remaining (c. 50 ha) area of the catchment as part of the Waiwhakareke Natural Heritage Park. It is intended that the other 16ha of land will remain as pasture or be developed for residential housing (Duggan 2012b).

The lake receives water from four inflows and discharges into Lake Rotokauri via the Rotokauri/Te Rapa Drain, which was constructed in the 1940's (Duggan 2012b; McQueen 2005). This drain accounts for 60% of the catchment of Lake Rotokauri and is a key source of sediment and nutrient transfer into this lake (Warr 1998).

Various information exists about the water quality of Lake Waiwhakareke. The lake is currently classified as hypertrophic on the basis of the most recent data collected by Duggan (in HCC Management Plan 2010). Phosphorus is thought to be the limiting nutrient for phytoplankton growth in the lake, with large amounts derived from the bottom sediments of the lake during times of deoxygenation.
Waikato Regional Council does not hold any further water quality information for this lake but has recently added the lake to its bimonthly water quality monitoring programme so will be collecting water quality data in future.

	Mean SD (m)	**Mean Chl *a* (mg m^{-3})**	**Mean TN (mg m^{-3})**	**Mean TP (mg m^{-3})**	**Estimated TLI**	**pH**	**Turbidity (NTU)**
1977[a]	0.45	31.5					
1988[b]	0.90	44.85	1485	45		7.1	
1992[c]	1.2	73	1170-1265	73-91			
2001[d]	1.0						
2006-2008[e]	0.95	57.2	1566	95.8 *			
2006-2007[f]	0.87	49.97	1554	94.7			
2007-2008[f]	1.00	62.31	1558	97.3			

Chapman & Boubee (1977)

b Page (1988) Mean of two samples taken between December 1987 to March 1988

c Pridmore (1992)

d Champion et al. (2001b)

e monthly averages of sampling carried out by the University of Waikato (Duggan) – reported in HCC Management Plan (2010).

* note error in TP concentration reported by HCC (2010)

f Duggan (2012)

The submerged plant communities of Lake Waiwhakareke appear to be very limited. In 2001 NIWA staff reported that the submerged vegetation consisted only of small areas of milfoil (*Myriophyllum propinquum*) in shallow water at the western end of the lake (Champion et al. 2001b). Pollen records and other studies indicate that the lake would historically have been dominated by native charophytes, pondweeds and milfoils (HCC 2010). A significant (8m x 2m) patch of sphagnum moss, a major species in peat formation, exists on the western arm of the lake (HCC 2010). The lake margin semi-swamp has been planted (during 2004-2006) in manuka-flax type vegetation as part of the Waiwhakareke Natural Heritage project.

Lake Waiwhakareke supports a range of common birds and waterfowl species, along with populations of native eels (long and shortfin eels), inanga, smelt and common bullies. A relict population of giant kokopu occurred in shaded areas of the drain downstream of the lake in 2001, and this species may also occur in low densities in the lake. The management plan for the Natural Heritage Park indicates that the threatened black mudfish may also be translocated to the lake in future (HCC 2010). Several exotic fish species, including rudd, brown bullhead catfish, brown trout, and *Gambusia* have

also been recorded from the lake during surveys undertaken by Champion et al. (2001b) and the University of Waikato (reported in HCC 2010). Koi carp and goldfish have not been reported from the lake to date.

An operative management plan exists for the Waiwhakareke Natural Heritage Park (Hamilton City Council; 2011). This plan specifies goals for the creation of a Natural Heritage Park (NHP) that represents the original ecosystem diversity of the Hamilton Basin, including extensive retirement and restoration of the lake margins and wetland areas.

Duggan (2012b) prepared a simple nutrient budget for Lake Waiwhakareke, and projected that the lake's water quality would improve to a mesotrophic state with the proposed conversion of 76% of the lake's catchment to permanent native forest as part of the Waiwhakareke NHP. This improvement can be expected to occur over a 10-20 year period once a new phosphorus equilibrium is established.

Lake Waiwhakareke is also included in the Rotokauri Structure plan developed by Hamilton City Council in 2002. This plan provides an assessment of the opportunities and constraints for land use change in the Rotokauri area with the objective "To manage all land use and development activities in the area to protect and enhance Lakes Rotokauri and Waiwhakareke".

The main threats to Lake Waiwhakareke include poor water quality, future stormwater arising from development within part of the lake's catchment, and the potential effects of invasive freshwater fish on native submerged plant communities and water quality. Previous authors (e.g. Pridmore 1992) have also expressed concern about the maintenance of lake and ground water levels to retain the peat/wetland area surrounding the lake. The water level of the lake is controlled by the height of Lake Rotokauri.

Options for management and acquisition of information:

- where possible, assist Hamilton City Council to implement the activities within the management plan for the Waiwhakareke Natural Heritage Park that relate to Lake Waiwhakareke and are within WRC's mandate (led by Hamilton CC)
- participate, as required by Hamilton City Council, in the implementation of the Rotokauri Structure Plan to ensure that the Lake Waiwhakareke goals are achieved.
- monitor the water quality of Lake Waiwhakareke over the long term through WRC's Shallow Lake Health Indicators Programme to assess the effectiveness of the lake restoration programme

3.2 Hauraki district

3.2.1 Kopuatai Burn Pools

Depth	Unknown
TA	Hauraki District Council
WRC zone	Waihou Piako
Land tenure	Private land
Lake area	Approximately 2ha
Estimated catchment area	183.10 ha
Catchment land use	Indigenous vegetation
Percent native vegetation cover in catchment	100%
Applicable joint agency accord/MOA	✕
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✓ within the Kopuatai peat dome
Identified as Priority 1 stock exclusion	✓

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (2)	Lake type (36)	WRC zone (4)
Data deficient	Data deficient	Data deficient	Data deficient
Figures in brackets indicate the total number of lakes included in assessment.			

Waikato Regional Council holds no water quality information for these small peat lakes, and little is known about their ecological values, although they are likely to be high due to their proximity to the Kopuatai peat dome.

It is understood that QEII recently sought to achieve a 300 ha covenant for the property that the lakes are located on, but this process was not completed.

It is understood that the lakes are deeply peat stained, with a narrow fringe of marginal willows. From aerial photos, it appears that specimen trees (e.g. oaks) are sparsely planted around the lakes – presumably as a food source for waterfowl. Other wetland vegetation surrounds the lakes, with some tracking evident from aerial photographs which are likely to provide access for duck shooting.

The lakes fall within the area associated with the Kopuatai peat dome that is identified to be in its natural state, an indigenous fishery, and a Priority 1 stock exclusion area for the purposes of the WRP. The lake margins do not appear to be fenced, but are surrounded by indigenous vegetation.

As a data deficient lake with potentially high values, it is a priority for Waikato Regional Council to visit these small lakes and assess their current condition.

Options for management and acquisition of information:

- Seek approval to visit the property to assess the lakes and their management requirements;
- Collect relevant information to enable the Kopuatai Burn Pools to be scored using the 'Methodology for ranking lake ecosystems for lake ecosystems for biodiversity management in the Waikato region' to enable its inclusion in the SNA Lake Ecosystems assessment;
- Consider for future monitoring in WRC's shallow lake health indicator programme

3.3 Matamata- Piako district

3.3.1 Leesons Pond

Depth	unknown
TA	Matamata-Piako District Council
WRC zone	Waihou Piako
Land tenure	Private
Lake area	3 - 4 ha
Estimated catchment area	Unkown (but small)
Catchment land use	dairy
Percent native vegetation cover in catchment	7.97
Applicable joint agency accord/MOA	✕
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 Stock Exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (1)	Lake type (36)	WRC zone(4)
38	1	23	1
Figures in brackets indicate the total number of lakes included in assessment.			

Leeson's pond is a small (3-4 ha), privately owned peat lake that is located within a small agricultural catchment just east of the Tauhei-Motumaoho Road near Morrinsville.

The lake is isolated from other natural areas, but is fully fenced with a wide marginal and wetland zone (ranging from 20–100m) that is dominated by grey willow (Wildland Consultants 2011a). It is understood that the water levels of the lake are managed to maximise available open water habitat for waterfowl and that the lake is managed by its current owners for hunting purposes. (Wildland Consultants 2011a).

Waikato Regional Council holds no water quality information For Leeson's Pond, but it is likely that the lake trophic status will be at least eutrophic given the nature of the surrounding landuse and the presence of high numbers of water fowl at the lake.

No information is available about native and introduced fish and plant species that occur within the lake. Anecdotal reports indicate that the lake may be vulnerable to greater

drainage and nutrient inputs if ownership changes in future, and that there may be scope to undertake weed control and planting to improve the biodiversity values of Leeson's pond (K. Hutchinson, *pers. comm.*).

Since Council holds no information about this lake, it is a priority for Waikato Regional Council to visit Leeson's pond and assess its condition.

Options for management and acquisition of information:

- Seek approval to visit the property to assess the lakes and their management requirements;

3.4 South Waikato district

3.4.1 Lake Okoroire

Depth	at least 1.6m
TA	South Waikato District Council
WRC zone	Waihou Piako
Land tenure	Private
Lake area	3.5 ha
Estimated catchment area	147 ha (reported as 80 ha in Dean 2010)
Catchment land use	Dairy
Percent native vegetation cover in catchment	0.02%
Applicable joint agency accord/MOA	✕
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 Stock Exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (1)	Lake type (36)	WRC Zone (4)
Data deficient	Data deficient	Data deficient	Data deficient
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Okoroire is a privately owned peat lake that is situated to the north-east of Tirau. The lake receives inflows from two drains, and has a single outlet drain that is piped some 120m before it enters Mangawai Stream which flows into the Waihou River (Dean 2010).

Waikato Regional Council had not visited the lake until 2010 when it jointly funded (with South Waikato District Council) the development of a restoration and management plan for the lake. The plan aims to enhance the natural character and biodiversity of the lake while minimising nutrient and sediment losses from the surrounding catchment and land use (Dean 2010). It describes the current condition of the lake and the key threats to it, and includes detailed planting and monitoring plans.

Lake Okoroire has been significantly altered as a result of surrounding land uses. The lake level has been lowered, and the lake receives substantial amounts of sediment and nutrients from surrounding land. Maize cropping occurs around half of the lake within close proximity to the lake and inflowing waterways

Lake Okoroire was sampled as part of Waikato Regional Council's shallow lake health indicator programme in 2011/2012. These results are summarised below and confirm that the lake is extremely nutrient enriched (hypertrophic).

	Mean SD (m)	**Mean Chl *a* (mg m^{-3})**	**Mean TN (mg m^{-3})**	**Mean TP (mg m^{-3})**	**Estimated TLI**	**pH**	**Turbidity (NTU)**
2011/2012[a]	0.56	86	2175	188	6.51	7.06	13.73
a WRC shallow lake health indicators programme (December/March/May)							

The landowners have obtained funding from Fonterra and the Biodiversity Condition Fund (Department of Conservation) to implement Dean's (2010) management and restoration plan for Lake Okoroire, with support from Waikato Regional Council, South Waikato District Council. Under this programme, the following works were to be undertaken between 2013 and 2016:

- construction of silt traps to intercept run off from farm land (planned for 2013);
- construction of an outlet weir to maintain a minimum summer lake level;
- control of weeds including water lilies, willow, alder, wattle, privet, Japanese honeysuckle etc (planned for 2013);
- establishing indigenous plants;
- establishing possum and rat bait stations.

Using available funding and a substantial amount of volunteer labour, the landowners have undertaken a considerable amount of physical works at Lake Okoroire, involving: removal of jetty structures; installation of small silt traps on the 2 lake inflows; willow removal, aerial spraying of submerged and emergent plants to remove waterlilies, mechanical clearance and planting of 9200 trees around approximately half of the lake margin.

The landowners have utilised novel methods to undertake this work that have involved considerable physical works on the lake margin for weed and willow clearance, and weedmat being laid over one quarter of the lake margin for weed control. Significant areas of kuta (*Eleocharis sphacelata*) have also been lost from the shallowest arm of the lake.

The landowners have indicated a desire to dredge and effectively deepen the lake to remove silt and water lily root structures and create more open water, and they are likely to seek resource consents for this activity. Further efforts would be required to reduce sediment and nutrient losses from surrounding land to maintain the benefits of dredging, if undertaken. Additional willow control and planting is also planned, and removal of the weedmat is intended after the plants have grown sufficiently. Waikato Regional Council is providing advice to the landowners on future plans and to support and encourage the application of best practice methods in future.

WRC is also assisting the landowners to determine a suitable minimum water level for Lake Okoroire. Whilst Lake Okoroire is not identified in section 3.7.4.5 of the WRP for lake level setting, water levels have been substantially lowered in the past and are vulnerable to further change. As a result, the lake is a higher priority than originally thought for lake level management (Wildland Consultants, 2009). The omission of this

lake from the WRP appears to have been due to a lack of information about the lake at the time.

Lake Okoroire is not identified as a priority stock exclusion area in the WRP, but is currently fully fenced.

Options for management and acquisition of information:

- provide assistance to the landowners where possible to implement the restoration and management plan for lake Okoroire (i.e. Dean 2010)
- re-survey lake health indicators in WRC's shallow lake health indicators programme
- assist the landowners to undertake a lake level setting exercise for Lake Okoroire, and incorporate the minimum lake level in Waikato Regional Plan (s. 3.2.4.7).

3.5 Waikato district

3.5.1 Lake Areare

Depth	5.1m
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Wildlife management reserve managed by Department of Conservation
Lake area	33 ha
Estimated catchment area	262 ha
Catchment land use	Dairy with some lifestyle
Percent native vegetation cover in catchment	0%
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✓ 22.5m Moturiki Datum
Identified as significant wetland (WRP Rule 3.7.7)	✓
Identified as Priority 1 stock exclusion	✓

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (36)	WRC zone (29)
19=	8	10=	6=
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Areare is located 3 km north of Horotiu within a pastoral catchment, adjacent to the former Kainui Peat Bog. With a surface area of 32 ha, Lake Areare is the largest of the Horsham Downs peat lakes.

Waikato Regional Council holds little water quality information for Lake Areare. In 1980 the lake was described as being eutrophic with a mean summer secchi depth of 0.5 m (Town, 1980). Lake Areare was visited again in December, March and May in

2010/2011 in the Waikato Regional Council's shallow lake health monitoring programme. The results obtained in 2010/2011 indicate that the lake is extremely nutrient enriched (i.e. hypertrophic).

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
1980[a]	0.4-0.6					6.3-7.0	
2010/2011[b]	0.48	45	2757	150	6.35	6.63	18.73
a Town (1980); WVA based on 10 samples taken between 7 January and 12 March 1980 b WRC shallow lake health indicators programme (average of December, March, May samples)							

Lake Areare is currently devegetated and has been for some years, although it is unknown when the submerged vegetation collapsed. In a detailed plant survey in 1991, an area of sparse aquatic vegetation was observed at 1 of 5 sites within the lake (Champion et al. 1993). Edwards et al. (2008) suggest that the lake is likely to have remained in a devegetated condition due to the heavy peat staining of the lake water, and intensification of surrounding land use.

While catfish, goldfish and *Gambusia* have been recorded from the lake, koi carp and rudd are thought to be absent. Their absence could significantly enhance the restoration potential of Lake Areare. DOC is currently working with Waikato District Council to survey the lake outlet to the Waikato River and redesign the road culvert immediately downstream of the lake (J. Gumbley, pers. comm.).

In 2003 when lake levels were already low, the outlet drain from Lake Areare was unlawfully lowered. Fish kills and algal blooms were also observed around this time. Waikato Regional Council subsequently obtained a resource consent to remove an existing structure. A timber weir was installed in the lake outlet in 2005 at 22.5m Moturiki datum - the minimum height identified in the WRP. After significant leakage problems, a new and wider structure was designed and installed in March 2008 to replace the original structure. This design has achieved a better seal around the weir edges and has been much more effective at achieving the minimum lake level. WRC has met its lake level monitoring obligations in respect of the resource consent for the weir and ceased lake level monitoring in 2013.

The lake has been fully fenced to exclude stock. DOC began fencing and replanting the (public land) lake margin in 2000. Approximately 3 hectares have now been replanted with (c. 30,000) indigenous plants with assistance from Waikato District Council, Fish & Game and the Living Legends project. There is scope for further planting to occur in this area, and to extend the restoration planting further around the lake (Wildland Consultants 2012a).

Lake Areare receives water from its agricultural catchment via 5 inflowing drains. A 7500m^2 constructed wetland has been constructed on the largest inflow to the lake (that drains more than half of the catchment) by NZ Transport Authority to mitigate the effects of the new Horotiu-Taupiri section of the Waikato expressway that is located adjacent to the lake. The wetland has been designed to capture sediments and other contaminants in less than 5 year flood events, but is unlikely to be effective at higher flows.

Significant progress has been made at Lake Areare in recent years. The entire lake margin has been fenced, and DOC and Waikato District Council have developed a carpark and public entranceway. DOC have also undertaken a considerable amount of weed control and successfully planted around 30,000 plants with volunteer labour. Almost 60% of the lake margin has been replanted with indigenous plant species

although the width of the planted margin is narrow in places, and a limited range of plant species have been used (Reeves 2012a).

Lake Areare was identified as the highest priority site for the Waikato Lakes & Freshwater MOA Group to establish a collaborative restoration project (Reeves & Carrodus 2012). An Inter-Agency Action Plan was subsequently developed for Lake Areare by the MOA Group that formed the basis of a successful funding application to the Waikato River Authority Clean Up Trust (Reeves 2012a).

The DOC-led project involves the following activities to be undertaken in 2013-2016:

- development of 1.4 ha treatment wetlands on 4 lake inflows;
- development and implementation of a habitat restoration and enhancement plan for 3.15 ha of new wetland and lowland forest, and enhancement of 1.5 ha of the re-vegetated areas;
- establishment of 0.5 ha of vegetation for cultural harvesting; and
- scoping of a detailed design plan for Lake Areare to provide for increased public access and recreational usage of the lake and its surrounds.

Waikato Regional Council are providing financial support for this project, and have committed to ongoing monitoring of shallow lake health indicators for the duration of the project.

Lake Areare has also recently been selected as a candidate site for a 10 year restoration programme in a conservation – dairy industry partnership initiative between DOC and Fonterra. The project plan for this work has been developed for work to begin in 2014/15. It seems likely that this project will be focussed on working with landowners in the wider catchment of Lake Areare to reduce nutrient and sediment losses from their properties, and biodiversity related projects. A bathymetric survey of Lake Areare has recently been undertaken as part of this project to create an updated bathymetric map.

Options for the management of Lake Areare and acquisition of information include:

- supporting DOC and other MOA Group members to implement the “Lake Areare Restoration & Enhancement” project funded by the Waikato River Clean Up Trust (to be led by DOC) and the wider Lake Areare Inter-agency Action Plan;
- regular survey of shallow lake health indicators to assess the effectiveness of restoration efforts at Lake Areare.
- support for the catchment management programme being undertaken at Lake Areare through DOC-Fonterra Partnership programme

3.5.2 Lake Hotoananga

Depth	3.5 m
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Part DOC wildlife management reserve/part private land
Lake area	19 ha
Estimated catchment area	71 ha
Catchment land use	Dairy
Percent native vegetation cover in catchment	0 %
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✓
Identified as Priority 1 Stock Exclusion	✓

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (36)	WRC zone (29)
18	5	9	5
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Hotoananga is a small waterbody located 3km east of Ngaruawahia township. The lake lies within a predominantly pastoral catchment and drains to the Waikato River via the Waikeri stream (Champion et al; 1993). The lake is also known as Munitions Lake as a result of the old munitions stores located on land adjacent to the lake. It is thought that munitions were dumped into the lake up until the mid 1980s (J. Gumbley, DOC *pers. comm.*).

Waikato Regional Council holds limited information about the condition of Lake Hotoananga. The lake was sampled in January-March of 1980 by Town (1980), and was reported to have high water transparency with secchi depth measurements being limited by the presence of beds of aquatic plants. Suspended solids and nutrient concentrations were also described as being very low at this time (Boswell et al., 1985).

The Department of Conservation carried out fish surveys in the lake during 2003, and reported that the water clarity was much greater than that in the other Horsham Downs peat lakes (Fergie, 2003). No additional water quality information is held by Waikato Regional Council, although the lake should be a high priority for data collection in light of the anecdotal reports of recent (high) water clarity and the presence of a comparatively large wetland margin.

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
1980[a]	1.2-2.3					6.3-9.2	

a Town (1980); WVA based on 10 samples taken between 7 January and 12 March 1980

The lake was reported to have been dominated by *Egeria* from the 1950s until the early 1990s. Town (1980) reported that *Egeria* grew across the entire surface of the lake bed. A Lake SPI assessment carried out in 2001 found no submerged plants despite observing good water clarity (Edwards et al. 2008). A cyanobacterial bloom was observed on the eastern shore of the lake, and increased turbidity was recorded during a further survey in 2010. During this visit, the charophyte *Nitella* aff. c*ristata* formed low covers (<25%) to a depth of 1m against reed beds (*Eleocharis sphacelata*), and *Potamogeton ochreatus* was also observed. Whilst there was low plant cover at some sites, the lake scored a default value of 0% during the 2010 survey due to a lack of submerged vegetation at the majority of survey sites (Edwards et al; 2010).

Threatened species recorded at the site include black shag, New Zealand dabchick and little black shag (Fergie, 2003). The only exotic fish recorded in the lake is *Gambusia*, but goldfish are also suspected, and there are unconfirmed reports of koi carp from the lake (J. Gumbley, DOC *pers. comm.*).

Lake Hotoananga is a Priority 1 stock exclusion waterbody. In 2009 WRC assisted adjacent landowners to retire and fence c.1km of the lake margin on the northern side of the lake. The Department of Conservation is currently working with adjacent landowners to ensure that the lake margin is fully fenced to an appropriate standard.

The invert level of the lake outlet drain was surveyed in 2008 to provide data to support drainage rules in the WRP. Lake Hotoananga is also identified in Section 3.7.4.5 of the WRP as requiring a minimum level to be set. To assist with lake level setting, Waikato Regional Council has been monitoring lake levels since April 2006.

In October 2009 WRC staff visited the lake outlet and observed that area at the outlet of the lake was very overgrown with willow and not particularly well formed. They concluded that the vegetation was likely to be acting as a control on lake water levels and that there was no imminent risk of lake lowering. As a result, lake level setting for Lake Hotoananga was considered to be a lower priority than for other lakes. However, DOC has since undertaken a willow control programme around the lake which may have affected lake water levels. The monitoring record is currently being reviewed in detail as lake levels appear to have dropped by at least 0.2m. If this proves correct, then a lake level setting process will need to be established for Lake Hotoananga as a matter of priority.

Key threats to Lake Hotoananga include continued stock access, catchment and downstream drainage, reduction of lake levels and exotic fish incursion.

Options for management and acquisition of information:

- develop relationship with key landowners including LINZ (in conjunction with other Waikato District Lakes & Wetlands MOA members)
- support landowners to fence and exclude stock from entire lake margin, and to better manage landuse (including drainage) as appropriate
- undertake a lake level setting process for Lake Hotoananga to establish a minimum lake level
- survey lake health indicators

3.5.3 Lake Kainui (Lake D)

Depth	6.7 m
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Recreation and esplanade reserve administered by Waikato District Council
Lake area	25 ha
Estimated catchment area	132 ha
Catchment land use	Dairy
Percent native vegetation cover in catchment	0%
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✓ 24.81 m (Moturiki Datum)
Identified as significant wetland (WRP Rule 3.7.7)	✗
Identified as Priority 1 stock exclusion	✗

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (36)	WRC zone (29)
31=	14	17=	13
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Kainui is managed by Waikato District Council through a Reserve Management Committee (Waikato District Council; 2011), and is utilised for a variety of recreational activities including hunting, water skiing, walking and picnicking. A management plan exists for the lake with a vision "To protect and restore the reserve's ecological values and enhance its recreational values for local and wider communities".

The water quality of Lake Kainui has been monitored sporadically over the last 30 years, initially by Waikato Valley Authority in 1980, then Waikato Regional Council in 1990 and 2003, and as part of a short term water quality study in 2007/08 (during a severe drought) by Waikato District Council. Lake Kainui has also been included in WRC's shallow lake health monitoring programme for 2012/13. Available water quality information is summarised in the table below.

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH
1980[a]	0.5-1.0					6.0-7.2
1990[b]		99		96		7.0
1990[c]	0.5	115		60		6.6
2003[d]	1.05	29	1645	107		7.1
2007/2008[e]		38.2	1582	73.8		7.16 (taken at 6m depth)

2009 [f]			1800	110		
2012/13 [g]	0.72	20.7	1558	84.3	5.7	

a Town (1980); WVA based on 10 samples taken between 7 January and 12 March 1980

b One sample taken by WRC at Located site 286_4 Northwest Surface in March 1990

c One sample taken by WRC at Located site 286_7 Southeast Surface in March 1990

d One sample taken by WRC at Located site 286_4 Northwest Surface in January 2003

e Averages for samples taken between November 2007 and March 2008 (5 samples). Waikato District Council (2011)

f Waikato University sampling results 18 September 2009 – B.Hicks pers. comm.

g WRC shallow lake health indicators programme (average of December, March, May samples)

Vegetation surveys of Lake Kainui in 1983 and 1991 failed to find any submerged plant species. However a survey in 2005 found that charophytes had established at three of five sites contributing to a LakeSPI score of 74%. This was the 5th highest score out of 43 Waikato lakes surveyed at that time (Edwards et al., 2008). A further Lake SPI assessment in 2010 found no submerged plants but urged caution in inferring lake condition change from changes in plant abundance. It is possible that periods of reduced humic colour inputs, from drainage, subsidence and carbon loss in the adjacent Kainui peat bog may allow for temporary development of plants (Edwards et al; 2010)

Threatened bird species recorded at the site include the black shag and little black shag (Fergie, 2003).

Lake Kainui is not identified a significant wetland or as a Priority 1 stock exclusion waterbody in the Waikato Regional Plan. Despite this, the lake is fully fenced to exclude stock with a margin of 20 – 35m. With funding assistance from WRC's Environmental Initiatives Fund (EIF) and the Honda Tree Fund, Waikato District have established native plantings and created silt traps on several inflowing drains within this area.

A minimum lake water level of 24.81m (Moturiki datum) is listed in the WRP for Lake Kainui – which represents the height of the invert level of the culvert that runs under Lake Road. However, drainage within the lake catchment is ongoing and landowners around the lake have expressed concern about high lake levels. Increasing pressure may develop to lower the minimum lake level and/or increase the capacity of the road culvert and outlet drain. As with all modified water courses, resource consent would be required to deepen the invert level of the outlet drain (Rule 4.3.4.4).

Waikato Regional Council surveyed land levels and the height of the invert of the outlet drain from Lake Kainui (including culverts and the fish barrier structure) in 2010 (Harrison Grierson), to assist with maintaining minimum lake levels.

Lake Kainui is known to support longfin and shortfin eels, catfish, goldfish, common bully, rudd and *Gambusia*, which were reported from an electrofishing trial that was undertaken by the University of Waikato in September 2009 (Waikato District Council; 2011). Koi carp have not been reported from the lake, which has a koi carp barrier on the outlet drain. However, this structure does not appear to have been maintained and there have been anecdotal reports of koi upstream of the structure in the last 2 years (Kevin Hutchinson, Rivercare, *pers. comm.).* The potential establishment of koi is a major threat to the lake as they would negatively impact on remaining submerged vegetation, and further aggravate the bank erosion; sediment resuspension and water quality issues that the lake experiences.

A recent PhD project by Rebecca Eivers (University of Waikato) was initiated in 2011 to assess the effectiveness of end of drain treatment systems such as silt traps, infiltration

filters and constructed wetlands in reducing sediment and nutrient inputs into lake systems. This work includes investigations of the existing silt traps at Lake Kainui.

Other key threats to the lake include ongoing drainage and associated peat subsidence, and nutrient inputs from the intensively farmed catchment.

Options for management and acquisition of information:

- Advocate for Waikato District Council to establish status of koi barrier on outlet drain and carry out maintenance as required to maintain the barrier
- Support Waikato District Council to undertake ongoing weed control and planting around the margin of Lake Kainui lake margin
- Work with members of the Waikato District Lakes & Wetlands MOA Group and the Reserve Management Committee to establish and implement initiatives to reduce sediment and nutrient losses to Lake Kainui from its surrounding catchment;
- Add Lake Kainui in section 3.7.7. of the WRP by variation
- Survey lake health indicators

3.5.4 Lake Kaituna (Lake B)

Depth	1.3 m
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Wildlife management reserve administered by Department of Conservation
Lake area	12 ha
Estimated catchment area	580 ha
Catchment land use	Dairy
Percent native vegetation cover in catchment	0.92 %
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	Controlled by weir at Lake C outlet
Identified as significant wetland (WRP Rule 3.7.7)	✓
Identified as Priority 1 stock exclusion	✓

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (36)	WRC zone (29)
26=	12=	12=	12
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Kaituna is another of the Horsham Downs peat lakes that are situated north of Hamilton City and lie within the Kainui Peat Bog. The lake flows to the Waikato River via nearby Lake Komakorau and a network of drains (Champion et al; 1993).

Lake Kaituna was surveyed during summer 1983 and was described to be associated with some 40 ha of wetlands (Boswell et al., 1985), which may have included Lake

Komakorau. Today the combined wetland area of these two lakes (including open water) is 29 ha.

Lake Kaituna was most recently sampled during 2006-2007 by Waikato Regional Council as part of a project investigating indicators of shallow lake health. Based on the results obtained during this survey, the lake is considered to be hypertrophic (Neilson et al., 2007). Water quality information is summarised in the table below.

	Mean SD (m)	**Mean Chl *a* ($mg\ m^{-3}$)**	**Mean TN ($mg\ m^{-3}$)**	**Mean TP ($mg\ m^{-3}$)**	**Estimated TLI**	**pH**	**Turbidity (NTU)**
1983[a]	0.1-0.3			127		6.58-7.90	
2006/2007[b]	0.14	95	3950	400	7.3	7.3	56.7
2009 [c]	0.25		3200	190			

a Boswell et al (1985) Samples collected between January and February 1983

b Waikato Regional Council Shallow Lake Health indicators programme (pilot study) (December, January and March) (Neilson *et al.* 2007).

c Waikato University sampling results 14 May 2009 – B. Hicks pers. comm.

Vegetation surveys in 1992 and 2007 indicate that the lake has become devegetated and that poor water clarity and the presence of koi carp have impeded plant establishment (Edwards et al., 2008).

Threatened species recorded at the site include little black shag, black shag, New Zealand dabchick and Australasian bittern (Fergie, 2003). Giant kokopu (*Galaxias argentus)* have also been found recently in one of the silt traps at this lake. Black mudfish have also been successfully translocated to the site.

The lake has been the focus of a substantial riparian restoration project over the past 10 years that has been largely driven by the Hayes family and a local Care Group. As a result, the lake is now fully fenced with a 20-80m margin (Michelle Hodges, Waikato Regional Council, pers. comm.). Other works include weed control, planting of native species and construction of silt traps on inflowing drains which have significantly enhanced the biodiversity values of the lake margin. Despite this, TP in the lake is now 3 times greater than it was in 1983 which is likely to reflect the effects of koi carp, and catchment modifications including drainage and land use changes.

The invert level of the lake outlet drain was surveyed by WRC in 2008 to provide data to support WRP rule 3.7.4.6. The lake level is controlled by a weir on the outlet of Lake Komakorau, which controls the water levels of Lakes Komakorau and Kaituna.

A PhD study is underway at Lake Kaituna investigating the efficacy of end of drain treatment systems such as silt traps, infiltration filters and constructed wetlands in reducing sediment and nutrient inputs into lake systems. This project has recently been extended to include a study of the effectiveness of floating wetlands that have been installed within two existing silt traps to further increase sediment and nutrient removal.

The adjoining landowners (the Hayes family) have played a vital role in the restoration of the lake margins and have modified their farming operation to best practice standards to reduce nutrient losses to the lakes. They have adopted the recommendations of a Whole Farm System & Environmental Management Plan that was prepared (and regularly updated) for them to reduce soil and nutrient losses to the lake whilst maximising efficiency and farm profitability.

The key remaining threats to the lake are the presence of koi carp and other pest fish, nutrient inputs from the very large primarily pastoral catchment, and shrinkage of surrounding peat due to catchment drainage. The lake is now very shallow and often floods low lying areas of farm land over winter, which may influence the short-medium term sustainability of farming around the lake.

Options for management and acquisition of information:

- advocate and support where possible ongoing weed control and planting around lake margin being undertaken by Department of Conservation and the Lake Kaituna Care Group
- continue to support investigations into the performance of silt traps and floating wetlands on nutrient removal on inflowing drains
- encourage initiatives to further reduce sediment and nutrient losses to Lake Kaituna from its surrounding catchment;
- repeat survey of lake health indicators.

3.5.5 Lake Komakorau (Lake C)

Depth	<1.0 m
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Wildlife management reserve administered by Department of Conservation
Lake Area	2.6 ha
Estimated catchment area	619 ha
Catchment land use	Dairy
Percent native vegetation cover in catchment	1.59%
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✓ 21.95 m (Moturiki Datum).
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✓

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (36)	WRC zone (29)
45	19	27	19
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Komakorau is another of the Horsham Downs peat lakes that lies to the North of Hamilton within the historic Kainui Peat Bog. The lake is situated close to Lake Kaituna and receives water from it (Champion et al; 1993).

Waikato Regional Council does not hold any water quality data for Lake Komakorau and the lake has not been surveyed for health indicators. However, given its proximity to Lake Kaituna and the hydrological connection between the lakes, it is assumed that water quality will be similar (i.e. hypertrophic). Surveys for submerged plants in 1992 and1993 indicated that the lake was devegetated (Champion et al. 1993) and it is presumed that the lake remains in this condition. There have been no further surveys since this time.

Lake Komakorau is fully fenced with a margin ranging in width from 15 - 120m (Michelle Hodges, WRC, pers.comm.). WRC has contributed to the costs of c.600m of fencing as at 2014. The Hayes family have previously expressed interest in having a QEII covenant (or similar) on the portion of the lake and wetland that they own (J.Gumbley, DOC, *pers. comm.*).

Lake Komakorau is included in the same DOC reserve as Lake Kaituna. However, Lake Komakorau is not specifically named in section 3.7.7. of the WRP and its portion of the reserve appears to have been removed from the defined area (for Lake Kaituna) that is described in section 3.7.7. As a result, it appears that Lake Komakorau is not subject to the rules that limit drainage within 200m of its reserve boundary.

A minimum water level of 21.9m is set in section 3.2.4.7 of the WRP for Lake Komakorau. The lake level has been controlled by a weir on the outlet since 1994. The original weir was constructed by DOC and was constructed of rock/rubble and set at a height of 21.9 m. In 2007, a new rock and concrete weir was constructed by the Department of Conservation as the previous weir had sunk by more than 50cm due to drainage and peat shrinkage. However, the new weir was problematic, and in 2009 Waikato Regional Council constructed a wooden v-notch weir in the outlet of Lake Komakorau at a height of 21.95 m (Moturiki Datum).

This weir also establishes a minimum level for Lake Kaituna, which is included in section 3.7.7 of the WRP and subject to drainage rules 3.7.4.6. To support the implementation of this rule, the invert level of the lake outlet drain was surveyed in 2008.

Threats to Lake Komakorau include drainage, koi carp, nutrient and sediment inputs, and peat shrinkage. This lake is very shallow with low lying farmland along the eastern and southern margins. The ongoing sustainability of farming operations in these areas is questionable given the current levels of peat shrinkage. However there has been substantial wetland restoration work carried out around the lake over the last decade, which has resulted in considerable biodiversity gains.

Options for management and acquisition of information of Lake Komakorau include:

- Vary section 3.7.7. of the WRP to include Lake Komakorau
- Support where possible ongoing weed control and planting around the lake margin being undertaken by Department of Conservation and Lake Kaituna Care Group;

- Encourage initiatives to further reduce sediment and nutrient losses to Lake Komakorau from its surrounding catchment;
- Support options to protect private land associated with Lake Komakorau (e.g. QEII covenant);
- Survey lake health indicators,

3.5.6 Lake Pikopiko

Depth	2.5 m
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Wildlife management reserve administered by Department of Conservation
Lake area	6.4 ha
Estimated catchment area	94 ha
Catchment land use	Dairy
Percent native vegetation cover in catchment	0%
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✓ 20.0m (Moturiki datum) - Variation for inclusion in the WRP (section 3.7.4.5)
Identified as significant wetland (WRP Rule 3.7.7)	✓
Identified as Priority 1 Stock Exclusion	✓

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (36)	WRC zone (29)
39=	16=	24=	15=
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Pikopiko is situated approximately 3km east of Ngaruawahia township close to Lake Hotoananga. Both lakes drain to the Waikato River via the Waikeri Stream (Chapman et al; 1993).

Waikato Regional Council does not hold any water quality data for Lake Pikopiko. However given the surrounding land use and condition of other nearby lakes (in the Horsham Downs complex), it is likely to be eutrophic or hypertrophic.

A formal Lake SPI assessment has not been carried out at this site. The vegetation was surveyed in 1990/91 and found to be dominated by *Egeria densa* (Champion et al., 1993), but by 2002 the plants had collapsed and the lake was reported to be devegetated (Fergie, 2003).

The lake bed and a small area of lake margin is administered as a Wildlife Management Reserve by the Department of Conservation. Waikato District Council administers a road reserve and a 20m esplanade reserve that extends most of the way around the DOC reserve, and provides a more substantial riparian buffer adjacent to the lake.

Fencing at Lake Pikopiko has not been stockproof in the past, but most of the DOC reserve is now fully fenced. The esplanade Reserve (administered by Waikato District Council) is not fully fenced however. Stock exclusion from this would be desirable to extend the vegetated buffer between the lake and the surrounding land, and minimise the risk of further drainage activities close to the lake.

Some fencing and planting has been undertaken by landowners on inflows to Lake Pikopiko with assistance from Waikato Regional Council.

Lake levels were substantially lowered (by c.0.5m) in the early 1990s (Champion et al., 1993), and drainage is an ongoing threat to Lake Pikopiko, although it is listed in section 3.7.7 of the WRP and is subject to drainage rule 3.7.4.6. The invert level of the lake outlet drain was surveyed in 2007/08 and in 2009/10, which will provide useful information to support the implementation of rule 3.7.4.6 at this lake.

Lake Pikopiko is not identified in s. 3.7.4.5 of the WRP as a priority for lake level setting, but WRC staff visited Lakes Pikopiko and Hotoananga in October 2009 and concluded that the priority for a water level control structure was highest at this site (Keri Neilson, pers. comm.). Lake water levels have been monitored since April 2006 and a weir was constructed in the outlet drain in 2010 to maintain a minimum water level of RL 20.0m (Moturiki datum).

The weir was subsequently surveyed and found to be higher than authorised. This was remediated in April 2012 when the weir was re-cut to the correct height and further surveys have confirmed the weir is now at the correct level of 20.0m (Moturiki datum). Lake level monitoring will continue on this lake until 2015 as required by the resource consent.

Koi carp are not known from the lake and could represent a significant threat to the lake if they were to become established there. Blackberry is a major problem on the western lake margin, and crack and grey willow have invaded open water around much of the lake edge (Fergie 2003).

Options for management and acquisition of information:

- minimum lake level of 20.00 m (Moturiki datum) to be included as part of next variation to the WRP (Waikato Regional Council).
- advocate for and support other MOA agencies and landowners where possible to exclude stock from the lake margin (by fencing) along the district council esplanade boundaries (and DOC reserve where there is no district council reserve)
- advocate and support where possible ongoing weed control and planting around lake margin being undertaken by Department of Conservation, Waikato District Council and private landowners
- survey lake health indicators
- support initiatives to secure public/agency access to Lake Pikopiko
- support other agencies to minimise the risk (as far as practicable) of koi carp and other invasive fish entering the lakes.

3.5.7 Lake Rotokaraka

Depth	Unknown
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	
Lake area	c. 6-7 ha
Estimated catchment area	Unknown
Catchment land use	Unknown
Percent native vegetation cover in catchment	Unknown
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (36)	WRC zone (29)
Data deficient	Data deficient	Data deficient	Data deficient
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Rotokaraka is situated to the west of the settlement of Whitikahu.

WRC holds no information or water quality data for Lake Rotokaraka. The lake is understood to be very degraded, having been substantially drained and heavily invaded by willows (Prof D. Lowe, pers. comm.)

The sediment history of Lake Rotokaraka has been studied by Waikato University staff who have determined that the lake was formed around 20,000 years ago (Prof. D.Lowe, Waikato University, *pers. comm.*).

Options for management and acquisition of information:

- seek approval to visit Lake Rotokaraka to assess the lake and its future management requirements
- collect relevant information to enable Lake Rotokaraka to be scored using the 'Methodology for ranking lake ecosystems for lake ecosystems for biodiversity management in the Waikato region' to enable its inclusion in the SNA lake ecosystems assessment.

3.5.8 Lake Rotokauri

Depth	4.0m
TA	Waikato District Council
WRC zone	Waipa
Land tenure	Recreation reserve administered by district council/private land
Lake Area	41.7 ha
Estimated catchment area	933 ha
Catchment land use	Urban/lifestyle/dairy
Percent native vegetation cover in catchment	0.24%
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✓ 22.5 m (Moturiki Datum
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (36)	WRC zone (15)
26=	12=	12=	7
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Rotokauri is a moderately large lake that receives inflows from a 933 ha catchment that is used for residential, industrial and farming purposes and also includes nearby Horseshoe Lake (Waiwhakareke). Lake Rotokauri discharges into the Ohote Stream which then flows on to the Waipa River.

Water quality measurements have been taken on several occasions, although the data is not continuous or comprehensive. Most recently, Waikato Regional Council collected monthly water samples from the lake between August 1997 and July 2002. No significant changes in SD, TP and TN were detected over this five-year period, although the lake's water quality had deteriorated significantly since c.1980. Barnes (2002a) reported that the lake has high concentrations of nutrients and phytoplankton and poor water clarity, which is indicative of a shift to a turbid, phytoplankton dominated state. On the basis of the most recent trophic lake index scores, Lake Rotokauri is considered to be hypertrophic.

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
1977[a]	1.0	4.4					
1980[b]	0.6-2.6					6.5-8.3	
1988[c]	2.2	23.14	725	25			
1997-2001[d]	0.6	79	1665	125	6.36		
2009 [e]			1000	49			

a Chapman & Boubee (1977)

b Town (1980); WVA based on 10 samples taken between 7 January and 12 March 1980

c Page (1988) Mean of two samples taken between December 1987 to March 1988

d Average of samples taken between August 1997 and 2001- Barnes (2002) – WRC data

e Waikato University sampling results 29 November 2011

The submerged vegetation in the lake has been surveyed on five occasions since 1977. In that time, the lake has transitioned from supporting a mix of native and exotic species (1977), to being completely dominated by the exotic oxygen weed *Egeria densa* (1990-91). This vegetation subsequently collapsed and the lake was reported to be devegetated in 1998 and remains this way today (Edwards et al, 2009). There are anecdotal reports that the collapse of the vegetation coincided with a sharp decline in water quality (Barnes, 2002a), which is consistent with trends seen in other shallow lakes. Waikato Regional Council has not studied other lake health indicators in Lake Rotokauri.

The lake has an extensive emergent plant zone that is dominated by raupo, and a reasonable diversity of native plants in the wetland zone. The emergent vegetation zone provides habitat for a range of wetland bird species and is buffered by a wide margin of willow and manuka scrub (Wildland Consultants 2009).

Lake Rotokauri is fully fenced to exclude stock and has been for many years. Fenced margins vary in width from 25-100 m and mostly comprise a district council local purpose (ecological management) reserve.

The level of the Ohote Stream has been significantly lowered by drainage activities, which has decreased the lake level by up to 5m and reduced the size of the lake to half of the size that it was in c.1860 (Hamilton City Council, 2000). The minimum level listed in the WRP represents the height of the weir situated in the lake outlet.

A new rock-rubble weir was installed in 2000 (replacing a previous vertical wall weir) in an effort to improve native fish passage into the lake. Large spawls were also placed below the weir in an attempt to exclude large undesirable fish. A survey of fish above and below the weir in January 2007 was inconclusive about the fish passage improvements achieved by the weir. Shortfin eels were captured both above and below the structure however no eels smaller than 300 m were captured in the lake, which may be a reflection of the sampling techniques used (McDonald, 2007). A subsequent electrofishing survey carried out in 2009 found shortfin eels in the lake between118 – 778 mm in size suggesting that small eels are moving over the weir (Brendan Hicks, unpublished).

Exotic species recorded from the lake are catfish, goldfish, koi, *Gambusia*, rudd and a koi/goldfish hybrid (Wildland Consultants 2009, WVA 1980, Warr 1998). Koi carp

represent an ongoing threat to the lake, and may impede in-lake restoration programmes.

Lake Rotokauri is located on the boundary between Waikato District Council and Hamilton City Council and its catchment is divided between these agencies. The Department of Conservation has delegated its authority to Waikato District Council to "control and manage" the reserve that surrounds most of the lake whilst Hamilton City Council administers a smaller area of reserve on the south eastern side of the lake. The lake is managed through the Lake Rotokauri Management Committee, which contains representatives from Councils, the community, and other agencies (including Fish & Game, DOC and Waikato Regional Council).

A detailed management plan was prepared for the area administered by Waikato District Council in 2000. Hamilton City Council also have a management plan for the area of the reserve they administer (Hamilton City Council; 2002) which is consistent with the Waikato District Council Plan.

In 2010, the Lake Management Committee presented a series of ambitious management objectives for the lake including nutrient and algal limits, and objectives for water clarity and recreational contact (Ben Wolf, Waikato DC pers comm.). Achievement of these objectives will likely require substantial management intervention. Jenkins & Vant (2006) modelled nutrient inputs to the lakes on the basis of surrounding landuses, and reported that N and P could be reduced by 7.7% and 13.4%, respectively by adopting best practice land management, and by 39.9 and 39.4% by adopting "potential" practices.

The Rotokauri Structure Plan was developed by Hamilton City Council in 2002 – which assesses opportunities and constraints for land use change in the Rotokauri area. This Structure plan identifies Lake Rotokauri as a key landscape feature of the Rotokauri area, and aims to "To manage all land use and development activities in the area to protect and enhance Lakes Rotokauri and Waiwhakareke". Several investigations have been undertaken in a staged manner between 2008-2012 to understand the effects of urbanisation and development (associated with implementation of the structure plan) upon the lake. These projects involving detailed monitoring and analysis, development and testing of hydrodynamic and water quality models, and assessment of treatment options to reduce nutrient inputs to the lake.

These projects conclude that the implementation of the structure plan will be modest in the context of the existing condition of the lake, but project a decline in water quality if actions are not taken to reduce nutrient inputs to Lake Rotokauri (Diffuse Solutions Ltd 2008, 2009, 2010, 2012; Sharma 2011). Modest water quality improvements are predicted if floodways, detention basins, and grassy swales are installed and maintained as part of the urabanisation process.

The modelling study also demonstrated the importance of groundwater inputs relative to surface inflows, and the role of flushing (as the lake has a relatively short residence time) in reducing the likelihood of algal blooms (Sharma 2011)

In recent years, the Lake Management Committee has overseen the construction of a silt trap on the major inflowing (Te Rapa) drain, extensive planting and weed control, and improved public access to the lake. This work has been undertaken largely by Waikato District Council with some external funding, including Environmental Initiatives Funding (EIF) from WRC.

Options for management and acquisition of information:

- encourage Waikato DC to monitor the effectiveness of the silt trap on lake inlet;

- encourage and support the Lake Rotokauri Management Committee to work with landowners within the lake catchment to improve land management practices and reduce nutrient and sediment losses to the lake;
- provide input/comment to Hamilton City Council in regards to development in the Rotokauri and Waiwhakareke area to enable the Rotokauri Structure Plan goals to be met for Lake Rotokauri;
- measure shallow lake health indicators; and
- support Waikato DC to undertake weed control and infill planting to improve biodiversity values at Lake Rotokauri

3.5.9 Lake Rotokawau (Black Lake)

Depth	1.2 m
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Stewardship land administered by Department of Conservation
Lake area	22 ha
Estimated catchment area	1804 ha
Catchment land use	Dairy/drystock
Percent native vegetation cover in catchment	33.73%
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✕ The Lake level is controlled by the level of Lake Waikare
Identified as significant wetland (WRP Rule 3.7.7)	✓
Identified as Priority 1 stock exclusion	✓

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (36)	WRC zone (29)
11	2	5	2
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Rotokawau lies to the south west of Lake Waikare and is connected to it by a (c.500m) channel (Boswell et al; 1985). The lake has been formed by peat deposition on 2 sides of the lake (that essentially acted as a dam), and is unique amongst the Lower Waikato lakes in that it is completely surrounded by a 145 ha wetland reserve administered by the Department of Conservation.

Water quality monitoring in the lake was carried out in 1983 by the Waikato Valley Authority (Boswell, 1985). At this time the lake was hypertrophic. Waikato Regional Council visited the lake over the summer of 2007/08 to survey for lake health indicators. The results indicated that the lake was still heavily nutrient enriched (hypertrophic), but

these surveys coincided with a severe drought so may not accurately reflect the lake's condition.

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
1983[a]	0.1-0.2	111		318		6.99	
2007/2008[b]	0.13	90	4315	645	7.51	7.35	80.5

a Boswell et al (1985) Samples collected between January and March 1983 – average of 6 samples

b Waikato Regional Council Shallow Lake Health indicators programme (December and March) Neilson and Hamer; 2008 (NB: Drought conditions)

The submerged vegetation of Lake Rotokawau has been surveyed on several occasions since the 1980s, and most recently in 2007. Although it was formerly dominated by native plants, the lake became devegetated in the 1990s and there has been no evidence of plant regeneration since (Edwards et al, 2009).

Black mudfish are known to exist around the margins of Lake Rotokawau, which has an extensive wetland margin that extends c.170 m to 600 m from the lake edge. Approximately 1 km of this wetland is thought to be unfenced.

As a result of its hydrological connection with Lake Waikare, and the altered water level controls established through the Lower Waikato Flood Control Scheme, lake levels in Lake Rotokawau and the extent of surrounding wetland have declined significantly since 1965 (Boswell et al, 1985). The remaining peat bog is rare and important in the lower Waikato area, as most bogs have been fully converted to pasture (Boswell et al. 1985)

In 2009 a new drain was created to divert the Frost Road drainage area into Lake Waikare directly to reduce nutrient inputs to Lake Rotokawau. The lake continues to receive inputs from the Lake Ohinewai catchment, however.

Key threats include ongoing impacts of nutrient inputs, water level controls on the wetland and the potential introduction of alligator weed which has been found both the nearby Te Onetea Stream and Whangamarino. Sedimentation has also been identified as a problem for Lake Rotokawau (as for Lake Waikare), and the main cause for shallow depth of the western basin (0.4-0.6 m deep).

Large numbers of koi carp have also been seen in Lake Rotokawau, which represent a major impediment to in-lake restoration.

Options for management and acquisition of information:

- support DOC and adjoining landowners to complete the fencing of the lake margin and adjoining wetland;
- work with members of the Waikato District Lakes & Freshwater Wetlands MOA group to identify future management options and restoration actions for the lake and surrounding wetland;
- support DOC to undertake regular surveillance for alligator weed and yellow flag iris at Lake Rotokawau;
- re-survey lake health indicators;
- encourage and support landowners within the lake catchment to improve land management practices and reduce nutrient and sediment losses to the lake.

3.5.10 Lake Te Kapa

Depth	Unknown
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Private
Lake area	1 ha
Estimated catchment area	Unknown
Catchment land use	Drystock/dairy (to be confirmed)
Percent native vegetation cover in catchment	Unknown
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (36)	WRC zone (29)
Data deficient	Data deficient	Data deficient	Data deficient
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Te Kapa is a small, privately owned peat lake that is fringed with raupo and surrounded by a c.15 ha vegetated wetland.

Waikato Regional Council has no historical water quality information for the lake, but sampled Lake Te Kapa in 2011/12 as part of the shallow lake health indicator programme. Details of these results are summarised in the table below, and indicate that the lake has very high level of nutrient enrichment (i.e. supertrophic).

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
2011/2012[a]	0.26	12	1683	93	5.85	6.46	23.46
a Waikato Regional Council Shallow Lake Health indicators programme (average of December, March, May samples)							

Ecological information about the lake is also scarce, although the vegetation surrounding the lake was assessed and prioritised for pest control by Wildland Consultants & Epro Ltd. in 1999. This report indicates that the wetland, at that time, was comprised mostly of manuka scrub with a small area of swamp cypress and pockets of willow (Wildland Consultants & Epro Ltd. 1999). Stock are reported to have had access to the marginal wetland when it was visited in 1999, which had modified the understorey and allowed invasive species such as royal fern and willow to establish, although willow was reportedly at relatively low levels.

Australasian bittern have previously been reported from the site and NZ dabchick were recorded from an adjacent pond in 1999. The lake and its associated wetland was assessed as having moderate to high wildlife values, which is enhanced by its proximity to Lake Waiwhata (Moynihan 1986; Wildland Consultants & Epro Ltd 1999).

Options for management and acquisition of information:

- collect relevant information to enable Lake Te Kapa to be scored using the 'Methodology for ranking lake ecosystems for lake ecosystems for biodiversity management in the Waikato region' to enable its inclusion in the SNA Lake Ecosystems assessment
- re-survey lake health indicators
- support landowners where possible to improve the condition of the wetland associated with Lake Te Kapa (particularly fencing & weed control)
- work with landowners in the lake's catchment to encourage best management practices on farm (including fencing & riparian management)
- advocate for the inclusion of Lake Te Kapa in the upcoming WRP reviews as a priority for stock exclusion.

3.5.11 Lake Tunawhakaheke (Lake E/ Tunawhakapeka/ Hurrell's Lake)

Depth	1.0 m
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Wildlife management reserve administered by the Department of Conservation/private land
Lake area	6.7 ha
Estimated catchment area	100 ha
Catchment land use	Dairy
Percent native vegetation cover in catchment	0%
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	29.655m (Moturiki Datum) – variation for inclusion in the WRP
Identified as significant wetland (WRP Rule 3.7.7)	✓
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (36)	WRC zone (29)
49	22	29	21
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Tunawhakaheke is a very shallow peat lake that is situated in Horsham Downs, north of Hamilton and immediately south of the Kainui Peat Bog. The lake is situated on public and private land, and has been extensively modified by drainage and agricultural activities within the catchment (Fergie 2003). The lake would previously have been a

closed system, but now has several small inflows, and drains into the Komakorau Stream and thenceforth to the Waikato River. The lake is situated within the Freshfield drainage district.

Champion et al. (1993) described the lake as eutrophic during his visits to the lake in 1989 and 1991, and observed the occurrence of algal blooms that were also described by Town (1980) who visited the lake in 1980. Water quality sampling was carried out by WVA early in 1980, when the lake had poor visual clarity and a faecal coliform count that made is unsuitable for contact recreation (Town 1980).

Waikato Regional Council sampled Lake Tunawhakaheke as part of the Shallow lake health indicator programme in 2011/12. Details of these results are summarised in the table below.

	Mean SD (m)	**Mean Chl *a* ($mg\ m^{-3}$)**	**Mean TN ($mg\ m^{-3}$)**	**Mean TP ($mg\ m^{-3}$)**	**Estimated TLI**	**pH**	**Turbidity (NTU)**
1980[a]	0.2-0.4					6.4-9.7	
2009[b]	0.32		2400	270			
2011/2012[c]	0.38	14	2047	281	6.22	6.9	28.03
a Town (1980); WVA based on 10 samples taken between 7 January and 12 March 1980 b Waikato University sampling 24 April 2009– B.Hicks pers. comm. c WRC shallow lake health indicators programme (average of December, March, May samples)							

No submerged aquatic plants[8] occurred in the lake in 2007, when it was last assessed by NIWA (Edwards et al. 2010). The lake was also de-vegetated during a previous survey that was carried out in 1991 (Champion et al. 1993), although it is likely to have supported extensive submerged vegetation in pre-European times (Edwards et al. 2010). It is not known when the vegetation collapsed in Lake Tunawhakaheke, but its shallow depth and the occurrence of algal blooms is likely to preclude plant recovery (Champion et al. 1993).

Lake Tunawhakaheke is utilised by a range of common waterfowl and wading birds including mallard ducks, grey duck, grey teal, paradise shelduck, pukeko, and black swans. Black shag, little black shag, and NZ dabchick have also been recorded from the lake, which are naturally uncommon and/or species of conservation significance. It is likely that these species move between Lake Tunawhakaheke and other Horsham Downs lakes that are in close proximity.

During a fish survey in April 2003, shortfin eel and goldfish were caught from the lake. Longfin eel may also occur in the lake, and local knowledge indicates that the lake was heavily populated with eels, carp, and catfish in the past (D. Collins pers. comm.). Fergie (2003) expresses concern about the potential impacts of koi carp if they reached the lake.

Fergie (2003) reported that the northern shoreline was stock proof, whilst the remainder of the lake margin was fenced with a sub-standard 1-wire electric fence that extended to the water's edge in some places. Since that time, the rest of the fences have been upgraded to a stockproof standard and relocated to the reserve boundary.

[8] A single rooted *Potamogeton crispus* specimen was identified during this visit – which is likely to have been spread via waterfowl

Until recently, the lake had a very narrow buffer around its margin with the northern shoreline dominated by grey willow and a southern shoreline predominantly in pasture with occasional patches of grey willow, weeping willow, pampas and pin oak (Fergie 2003). A large patch of raupo near the outlet drain in the north-eastern corner of the lake was reported to be the only emergent vegetation at the lake (Fergie 2003). Since then however, DOC has undertaken a considerable amount of planting and weed control on the newly fenced reserve on the Southern side of the lake.

New Zealand Landcare Trust has worked with local communities and landowners to develop a Catchment Action plan for Lake Tunawhakaheke, which involves fencing, willow removal, native planting, constructed wetlands and silt traps (NZ Landcare Trust 2010). As part of this process, whole farm system plans have been developed for 2 properties in the lake catchment to assist landowners to reduce the impacts of their farming operation on the lake by adopting more efficient soil, nutrient and effluent management practices.

Various structures have existed in the outlet drain to maintain lake levels since the 1940s (Dave Collins pers. comm.). It appears that the lake level dropped suddenly in the mid 1990s as a result of drain cleaning (D.Collins, pers. comm.) which raised concerns about reduced lake levels. A lake water level recorder was installed by DOC in June 2005 after the lake dried out completely during 2004. Waikato Regional Council assumed responsibility for maintaining this water level recorder in February 2006. These records indicate that the lake has regularly fallen below 0.5m depth, and has been completely dry in the summers of 2007/08, 2012/13 and 2014/14.

A v-notch timber weir was installed in April 2012 at a level of RL 29.655m (Moturiki Datum). The weir height has subsequently been confirmed by survey, and WRC continues to monitor lake levels to ensure that the weir operates effectively.

Surveys of the invert level of the lake outlet drain were completed in June 2008 to assist with the implementation of WRP rule 3.7.4.6 at this lake (Opus Consultants 2008). As part of the weir construction project WRC surveyed the lake outlet and the invert of the first 270m of the outlet drain in 2011 (Harrison Grierson 2011a).

The main threats to the lake include: peat shrinkage arising from drainage activities; weed invasion (particularly grey and crack willow, and pampas); stock damage to lake margins; and the impacts of existing and potential invasive fish species (including koi carp, catfish and goldfish). DOC has recently undertaken some work to control willows on the lake margin.

Options for management and acquisition of information:

- support DOC and adjoining landowners where possible to maintain the fencing and planting of the lake margin (including willow control);
- continue to monitor the water levels of Lake Tunawhakaheke to assess the effectiveness of the weir
- encourage NZ Landcare Trust to review progress against the farm management plans, and continue to support the care group where possible
- sample lake health indicators
- advocate for the inclusion of Lake Tunawhakaheke in the upcoming WRP reviews as a priority for stock exclusion.

3.5.12 Lake Waiwhata

Depth	Unknown
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Private land
Lake area	8.9 ha
Estimated catchment area	Unknown
Catchment land use	Dairy/drystock
Percent native vegetation cover in catchment	15%
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (36)	WRC zone (29)
Data deficient	Data deficient	Data deficient	Data deficient
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Waiwhata is a small privately owned peat lake that is almost completely surrounded by wetland. The lake is situated to the east of Lake Whangape, and to the north of Lake Rotongaroiti.

Waikato Regional Council holds no information about the water quality or ecological condition of the lake, and was not able to obtain landowner permission to visit the site in the Shallow Lake Health Indicators Programme in 2011/12.

The lake is known to be utilised by a range of common waterfowl species, and also the Australian bittern which is of conservation significance. The site was identified as a wetland of moderate-high wildlife value by Moynihan (1986)[9].

Moynihan (1986) described the lake as having extensive manuka margins that also contained cabbage trees, raupo, flax, *Coprosma* sp., sedges, and rushes. Pussy willow was also present at that time. The lake and its surrounding wetland have not been assessed for pest control because of access limitations (Wildland Consultants & Epro 1999).

It is unknown whether Lake Waiwhata and its marginal vegetation is accessible to stock.

Because there is insufficient information to rank Lake Waiwhata for its current biodiversity values, it is a priority to visit the lake and assess its current condition and management requirements.

[9] This assessment recognised the lake's proximity to Lake Te Kapa.

Options for management and acquisition of information:

- seek approval from landowners to visit Lake Waiwhata to assess the lake and its future management requirements
- collect relevant information to enable Lake Waiwhata to be scored using the 'Methodology for ranking lake ecosystems for biodiversity management in the Waikato region' to enable its inclusion in the SNA Lake Ecosystems assessment
- survey lake health indicators
- work with landowners in the lake catchment to encourage best management practices on farm (including fencing & riparian management)
- advocate for the inclusion of Lake Waiwhata in the upcoming WRP reviews as a priority for stock exclusion.

3.5.13 Lake Whakatangi (Lake A)

Depth	3.4m (from WRC data)
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Private land
Lake area	2.7 ha
Estimated catchment area	170 ha
Catchment land use	Dairy
Percent native vegetation cover in catchment	0%
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	26.84 m (Moturiki Datum) –Variation for inclusion in the WRP (section 3.7.4.5)
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (36)	WRC zone (29)
39=	16=	24=	15=
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Whakatangi is a small peat lake that is situated on private property in Horsham Downs, north of Hamilton. The lake receives direct inflow from the surrounding catchment via 5 inflowing drains. An outlet drain exists on the north-western side of the lake that discharges to Lake Kaituna before finally reaching the Waikato River.

The lake water was reported to be heavily peat-stained but of reasonable clarity in 1992 (Champion et al. 1993). Waikato Regional Council sampled Lake Whakatangi as part of the Shallow lake health indicator programme in 2011/12 and collected results that indicate that the lake has become nutrient enriched and is currently supertrophic. The results are presented below:

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
2011/2012[a]	0.72	8	3203	168	5.84	7.0	7.2
a WRC shallow lake health indicators programme (average of December, March, May samples)							

No submerged vegetation existed in the lake during surveys in 1992 and 2003, which was attributed to poor light conditions arising from peat staining and shade from overhanging willows (Champion et al. 1993, Fergie 2003). The lake was also reported to be de-vegetated when it was surveyed most recently (Fergie 2003). No Lake SPI surveys have been undertaken since that time.

The lake is utilised by a range of common waterfowl and wading birds including mallard ducks, grey duck, grey teal, paradise shelduck, and pukeko, and receives a high level of use for duck shooting. Little black shag, and NZ dabchick have also been recorded from the lake, which are naturally uncommon and/or species of conservation significance. It is likely that these species move between Lake Whakatangi and the other Horsham Downs lakes nearby.

Native shortfinned eels and common bully occur in the lake, along with pest fish species, rudd and *Gambusia*. There is also concern about the potential impact of koi carp if they were to reach the lake in future (Fergie 2003).

Fergie (2003) reported that the lake was fully fenced with a mixture of 6, 3 and 2-wire electric fencing. Whilst the 6 and 2-wire sections were found to be sound and stockproof, the 3-wire section on the southern side of the lake was reported to be sub-standard, and stock are known to gain access the lake margins periodically. Up to 400m of new fencing may be required to upgrade this section of the fence and prevent stock access to the lake.

The lake has a narrow vegetated margin which is limited by the placement of a track/race that runs around more than half of the lake, and comes close to the lake edge in places. The lake margin has been invaded almost entirely by grey willow, with several patches of privet interspersed amongst it. In 2003, the willow/privet understorey was described to be a mix of common native and exotic species, including the prolific weed Japanese honeysuckle that existed in several large patches at the time (Fergie 2003) but may have spread further since then.

In order to establish an appropriate minimum lake level, a water level recorder was installed by DOC in June 2005. Waikato Regional Council assumed responsibility for the recorder in May 2006 and data gathered between 2006-2010 indicated declining summer levels over this time with consistent winter peaks and an unusual pattern for lakes of this type.

Waikato Regional Council has undertaken a lake level setting process for Lake Whakatangi, and installed a v-notch timber weir in April 2012 at a level of RL 26.84m (Moturiki Datum). The weir height has subsequently been confirmed by survey, and WRC will continue to monitor water levels in Lake Whakatangi to ensure that the weir is operating effectively.

Whilst other Horsham Downs lakes (e.g. Lakes Kaituna and Tunawhakaheke) are included in section 3.7.7. of the WRP, Lake Whakatangi has been omitted from this section. This may be because the lake is privately owned, however, it may be appropriate to consider including Lake Whakatangi in this section in future variations of

the WRP. As part of the weir construction project WRC surveyed the lake outlet and the invert of the first 150m of the outlet drain in 2011 (Harrison Grierson 2011a).

The main threats to the lake include: peat shrinkage arising from drainage activities; weed invasion (particularly grey willow and Japanese honey suckle); stock damage to lake margins; nutrient enrichment from non-point source inputs; and the impacts of existing and potential invasive fish species (including koi carp, catfish and goldfish).

Options for management and acquisition of information:

- advocate and support where possible the Department of Conservation and adjoining landowners to fence and plant the lake margin
- consider including Lake Whakatangi in future Lake SPI surveys undertaken for WRC
- repeat sampling of lake health indicators
- advocate for the inclusion of Lake Whakatangi in the upcoming WRP reviews as a priority for stock exclusion and as a significant wetland.

3.6 Waipa district

3.6.1 Lake Cameron (Lake Kareaotahi)

Depth	1.5 m
TA	Waipa District Council
WRC zone	Central Waikato
Land tenure	Recreation reserve administered by Waipa District Council
Lake area	3.4 ha
Estimated catchment area	31 ha (or 26.6ha - Faithfull et. al. 2005)
Catchment land use	Dairy/lifestyle
Percent native vegetation cover in catchment	0%
Applicable joint agency accord/MOA	Waipa Peat Lakes Accord
Lake level in WRP	✓ 48.5 m Moturiki datum
Identified as significant wetland (WRP Rule 3.7.7)	✓
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (17)	Lake type (36)	WRC Zone (7)
33	13	19	3
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Cameron is a small peat lake that adjoins the Rukuhia peat bog on its south western margin. The lake and reserve occupy an area of 9.2 ha and are managed by Waipa District Council (Waipa District Council, 2007).

Waikato Regional Council has very little recent water quality data for the lake, although water quality measurements have been taken sporadically over the last 20 years. Summer sampling in 1997 (Thompson and Greenwood, 1997) and a single sample taken by Waikato Regional Council in 2004 indicated that TN and TP concentrations were in the range expected for a super-hypertrophic lake. Water quality data is summarised in the table below.

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
1977[a]	0.3	11					
1988[b]	0.25	199	3560	900		7.05	
1991[c]	0.55		2550	553		6.0	4
1997[d]			1438	350			20
2004[e]			864	512		5.08	

a Chapman and Boubee (1977)

b Page (1988) Mean of two samples taken between December 1987 to March 1988 – surface sample figures have been used for TP and TN

c Average of two samples taken by WRC at Located site 291_1 Eastern Shoreline – June and August 1991

d Thompson and Greenwood (1997) – based on 2 samples collected over a 10 day period during the 1997 summer. Results have been transposed from graphs so are indicative of values

e 2004 (Faithfull et al; 2005) Results based on one sample

A Lake SPI assessment has not been carried out at Lake Cameron however previous investigators have reported that the lake does not contain submerged vegetation, which has been attributed to low water clarity due to peat staining and high levels of turbidity (Thompson & Champion, 1993; Faithfull et al. 2005).

A sediment trap was constructed on the major inlet drain in 2001 in an effort to reduce nutrient and sediment losses to the lake (Tony Roxburgh, pers. comm.).

Thompson & Champion (1993) considered that drainage was an immediate threat to Lake Cameron, and that urgent work was required to retain an actively growing peat barrier along the lake margin. They (conservatively) recommended that an immediate esplanade reserve of 50-100m be established, with further extension within 25-30 years.

Waipa District Council has gradually extended the lake's marginal reserve by acquiring esplanade reserves during subdivision processes of surrounding properties. The margin varies in width from 50 m along the eastern boundary, to less than 20 m along the western boundary. It is this western margin of the lake that is considered one of the greatest threats to the lake's medium-long term survival due to high peat subsidence rates of the Rukuhia peat bog (Thompson & Champion 1993).

The Lake Cameron Care Group have planted most of the reserve surrounding the lake and undertaken weed control to the extent that most weed species now require a low level of maintenance to control.

Minimum lake levels are controlled by a culvert approximately 100 m downstream of the lake outlet. The invert height of this culvert is the height listed in the WRP as the minimum lake level. The invert level of the lake outlet drain was surveyed in 2007 to provide data to support WRP rule 3.7.4.6.

Lake Cameron is not listed in the WRP as a priority stock exclusion site, but is fully fenced to exclude stock.

Objectives listed in the Reserve plan for Lake Cameron include activities to establish and maintain buffer margins around the lake, set minimum levels and control drainage, control inflows of sediments and contaminants, manage introduced pests, promote recreational use, enhance habitats and protect historic sites (Waipa District Council; 2007).

Options for management and acquisition of information:

- support Waipa DC to acquire and retire land on the western lake margin where possible to extend the current lake margin and reduce peat shrinkage (Waipa Accord members)
- support Waipa DC to implement its Peat Lake Reserve Management Plan for Lake Cameron/Kareaotahi (Waipa Accord members)
- advocate and support Waipa District Council and the Lake Cameron Care group where possible to continue weed control and planting within lake reserve
- survey lake health indicators
- identify Lake Cameron/Kareaotahi as a priority site for stock exclusion in the WRP.

3.6.2 Henderson's Pond

Depth	Unknown
TA	Waipa District Council
WRC zone	Waipa
Land tenure	Private land
Lake area	0.88 ha
Estimated catchment area	31 ha
Catchment land use	Dairy
Percent native vegetation cover in catchment	0%
Applicable joint agency accord/MOA	Waipa Peat Lakes Accord
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (17)	Lake type (36)	WRC zone (15)
28=	9=	14=	8=
Figures in brackets indicate the total number of lakes included in assessment.			

Henderson's pond is a small lake that is privately owned under two separate titles. The lake is located near McGregor Road in Ohaupo/Rukuhia.

Waikato Regional Council holds no water quality data for Henderson's Pond and there is no record of staff ever having visited the lake. Page (1988) reported that the lake had very poor visual transparency with an average secchi depth measurement of 0.2 m, and chlorophyll a concentrations consistent with being supertrophic. Short term sampling by Thompson and Greenwood (1997) indicated that the lake was likely to be hypertrophic.

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
1988[a]	0.2					6.2	
1997[b]			1953	100			130
a Page (1988) Mean of two samples taken between December 1987 to March 1988 b Thompson and Greenwood (1997) – based on 2 samples collected over a 10 day period during the 1997 summer. Results have been transposed from graphs so are indicative of values							

Henderson's Pond has not been surveyed using the Lake SPI technique, and it is unknown whether submerged plants occur there.

The fencing status of Henderson's Pond is also uncertain. In 1997, the lake was reported to be half fenced off so that half of the lake had an adequate marginal wetland strip, whereas the other half was completely unfenced to enable stock to access the water's edge. Aerial photos taken in 2009 suggest that a fenced margin (c. 50m wide) may still exist along the eastern side of the lake, but that stock may still have access to the western lake and wetland margins.

A comparison of aerial photographs taken in 2002 and 2007 indicate that a substantial amount of new drainage works were undertaken in this period which has converted some the lake's previous wetland margins to pasture. Large drains appear to enter the lake directly with minimal vegetation or wetland buffers.

The lake is identified in Section 3.7.4.5 of the WRP as requiring a minimum level to be set. No progress has been made with this to date due to difficulties with accessing the property.

The lake has been described as very deep and associated with extremely deep (>8 m) acid peats (Thompson and Greenwood, 1997). Ongoing unrestricted drainage and nutrient loading from the catchment are considered to be the biggest threats to Henderson Pond.

Options for management and acquisition of information:

- develop relationship with key landowners
- advocate for and contribute where possible to fencing to exclude stock from the entire lake margin
- advocate to, and provide support for landowners to undertake weed control and planting within fenced margins

- undertake a lake level setting process for Henderson's Pond if the landowners' agreement can be obtained for access, analysis and water level control.
- assess drain configuration around the lake and work with landowners to improve nutrient removal from inflowing water (eg via sediment traps etc)
- survey lake health indicators.

3.6.3 Lake Koromatua

Depth	0.8 m
TA	Waipa District Council
WRC zone	Waipa
Land tenure	Wildlife management reserve administered by Department of Conservation
Lake area	9.9 ha
Estimated catchment area	200 ha
Catchment land use	Dairy
Percent native vegetation cover in catchment	3.35%
Applicable joint agency accord/MOA	Waipa Peat Lakes Accord
Lake level in WRP	✓ 39.13 m Moturiki Datum
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (17)	Lake type (36)	WRC zone (15)
31=	12	17=	11
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Koromatua lies on the outskirts of the Rukuhia Peat Bog and is situated south west of Hamilton city close to Templeview (Champion et al; 1993). The lake is located on a Wildlife Management Reserve, which is surrounded by a further 20m reserve administered by Waipa District Council. Beyond the reserves, the catchment land use is primarily dairy.

Lake Koromatua has been sampled sporadically since the 1970s. In 1997 the lake was reported to be hypertrophic with TP and TN concentrations similar to 1988 levels [that] were attributed to wastewater inputs (Thompson & Greenwood, 1997). The most recent water quality monitoring (in 2006/07) confirms that the lake has remained hypertrophic. This assessment was further supported by investigations of zooplankton communities at this time as part of Waikato Regional Council's Shallow Lake Health Indicators programme (Duggan, 2007).

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
1977[a]	0.05	282					

1983[b]	0.05-0.15	258		510		7.14	
1988[c]	0.1	243	4390	390		7.4	
1997[d]			3803	350			90
2002/2003[e]	0.21	195	3727	736		7.4	42
2006/2007[f]	0.25	359	4672	734	7.8	7.4	57.0
2009 [g]	0.19		2600	1000			

a Chapman and Boubee, 1978

b Boswell et al (1985) Samples collected between January and March 1983 – average of 6 samples

c Page (1988) Mean of two samples taken between December 1987 to March 1988 - – surface sample figures have been used for TP and TN

d Thompson and Greenwood (1997) – based on 2 samples collected over a 10 day period during the 1997 summer. Results have been transposed from graphs so are indicative of values

e Average of 8 samples taken by WRC at Located site 296_2 Centre surface between November 2002 and April 2003

f WRC shallow lake health indicators programme (pilot study) (December, January and March) (Neilson *et al.* 2007). (NB samples collected in drought conditions)

[g] University of Waikato sampling results 2 February 2009 – B.Hicks pers. comm.

Lake Koromatua was found to be devegetated when surveyed by NIWA in 1991 and was still in this condition when it was last surveyed in 2007. The absence of plants has been attributed to poor water clarity and the shallow nature of the lake (Edwards et al, 2009).

University of Waikato staff electric fished the lake in 2009 and reported only catching shortfinned eels. Significantly, they observed that the lakes appeared to be free of any exotic fish (Brendan Hicks, pers. comm.). Fish surveys conducted by DOC in 2007 and again in 2011 also found eels and the threatened black mudfish *(Neochanna diversus)* in wetland margins around the lake edge.

Lake Koromatua is fully fenced to exclude stock with a vegetated margin of c. 50-100m, although some public land is presently being leased for farming.

A weir was constructed by Hamilton Fish & Game on the outlet of the lake in 2001 and the height of this structure (39.13 m) is listed in the WRP as the minimum lake level. The lake level is currently monitored by Waipa District Council.

The lake has been the subject of the long-term and ongoing enhancement project by Hamilton Fish & Game and DOC. Works include fencing, willow control, silt trap construction, hydrological investigations, and animal pest control. In-lake restoration is however limited by depth and likely internal nutrient loads. Additional threats to the lake include ongoing drainage and land use effects from the surrounding farm land.

A PhD project has been established to investigate the efficacy of end of drain treatment systems such as silt traps, infiltration filters and constructed wetlands in reducing sediment and nutrient inputs into lake systems. This work includes investigations of the existing silt traps at Lake Koromatua.

The Koromatua Lake Committee has recently prepared a 5 year management programme for their future work at the lake and have received funding from WRA to construct a much larger silt trap (cf. previous traps) to treat water coming into the lake from the Koromatua drain.

Options for management and acquisition of information:

- advocate for and contribute where possible to ongoing plant and animal pest control and planting programmes being undertaken by Hamilton Fish & Game Association, Department of Conservation;
- encourage and support initiatives to reduce nutrient and sediment losses to the lake;
- consider inclusion in the WRP as a significant wetland , and as a priority site for Stock exclusion
- survey of lake health indicators.

3.6.4 Lake Mangahia

Depth	1.8 m
TA	Waipa District Council
WRC zone	Waipa
Land tenure	Private land
Lake area	8.4 ha
Estimated catchment area	354 ha
Catchment land use	Dairy
Percent native vegetation cover in catchment	3.87%
Applicable joint agency accord/MOA	Waipa Peat Lakes Accord
Lake level in WRP	✓ 36.8m Moturiki Datum
Identified as significant wetland (WRP Rule 3.7.7)	✓
Identified as Priority 1 stock exclusion	✓

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (17)	Lake type (36)	WRC Zone (15)
13=	5	6	3
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Mangahia is located near Ngahinapouri to the south-west of Hamilton City, adjacent to the Rukuhia Peat Bog (Champion et al; 1993). The lake is surrounded by developed peatland that is intensively farmed. Water enters the lake from the surrounding catchment and drains from the lake to the Waipa River via the Mangahia Stream. Lake Mangahia is privately owned with no public access.

The lake is a good example of a dystrophic lake with associated peat influenced vegetation. The lake catchment is primarily pastoral with intensive dairy land use (Bodmin et al, 2008).

Water quality of Lake Mangahia has been examined for varying periods of time on a number of occasions since the 1970s. Lake Mangahia has been sampled for the last 4 years (since 2009/10) as part of Waikato Regional Council's Shallow Lake Health Indicators programme. The water quality data is summarised in the table below, and indicates that the lake is hypertrophic, with extremely high total nitrogen and phosphorus concentrations.

	Mean SD (m)	Mean Chl *a* ($mg\ m^{-3}$)	Mean TN ($mg\ m^{-3}$)	Mean TP ($mg\ m^{-3}$)	Estimated TLI	pH	Turbidity (NTU)
1977[a]	0.3	12.9					
1982[b]	0.1-1.0	34.2		107.7		6.5	
1988[c]	0.35	120	1700	120		6.6	
1988-1994[d]	0.27	55	2403	197	6.57		
1997[e]			1734	150			75
2006/2007[f]	0.46	41	2919	673	6.9	6.9	26.2
2007/2008[g]	0.26	6	2520	790	6.5	7.3	41
2008/2009[i]	0.248	73	2861	653	7.15	6.8	63
2009[h]	0.15		3500	640			
2009/2010[i]	0.15	95	3221	720	7.43	7.1	72.66
2010/2011[i]	0.195	42	3730	746	7.12	6.36	36.73
2011/2012[i]	0.24	70	2875	570	7.09	6.6	46.66
2012/2013[i]	0.22	42	3115	597	7.04		

a Chapman and Boubee (1978)

b Town (1982b) weekly water quality sampling undertaken by WVA between January - March 1982

c Page (1988) Mean of two samples taken between December 1987 to March 1988 – surface sample figures have been used for TP and TN

d Average of samples taken between September 1988 and 1994- Barnes (2002a) – WRC data

e Thompson and Greenwood (1997) – based on 2 samples collected over a 10 day period during the 1997 summer. Results have been taken from graphs so are indicative values

f Waikato Regional Council Shallow Lake Health indicators programme (pilot study) (December, January and March) (Neilson *et al.* 2007).

g Waikato Regional Council Shallow Lake Health indicators programme (December/March) Nielson & Hamer (2008)

h Waikato University sampling results 4 February 2009– B. Hicks pers. comm.

i WRC shallow lake health indicators programme (average of December, March, May samples)

The lake was surveyed for aquatic plants in 1977, 1992 and 2007 but contained no submerged vegetation (Chapman & Boubee 1977; Champion et al. 1993; Edwards et al. 2009). It is thought that the strongly peat-stained water and probable presence of koi are likely to make conditions unsuitable for plant establishment (Edwards et al, 2009).

Thompson and Greenwood (1997) considered the lake to have the highest natural values of any of the Waipa peat lakes due to the high quality of wetland vegetation and its diversity of native species. Some of this vegetation has since been removed, but the lake still retained at least 41 native plant species including notable populations of parasol fern (*Gleichenia microphylla*) and regenerating kahikatea, which are rare and important features (Bodmin et al, 2008).

The fence around the lake has recently been moved and upgraded to exclude stock from a 40-120m wide margin. This fenced margin is comparatively wide in the context of other peat lakes regionally.

The lake level has been controlled by a concrete v-notch weir on the outlet since 2001 that was constructed following an alleged lowering of lake levels in 1999. The weir is

located approximately 80metres from the lake, at a location 5-6m downstream of a small sill in the bed of the drain.

The weir height was set in conjunction with other agencies and landowners. The invert of the v notch is set at 36.7m, which is 100mm below the minimum lake levels. This differential provides for a minimum low flow representative of low flow conditions. Lake level monitoring undertaken by WRC from August 2001 to January 2005 confirmed that the weir had maintained minimum lake levels above 36.8m.

As with most of the peat lakes, aerial photos indicate that Lake Mangahia is smaller now than it would have been historically, as a result of marginal vegetation (mostly grey willow) encroachment and lower lake levels. Because of the wide margins at this site, Lake Mangahia is one of the few sites where a substantial increase in minimum lake level may be acceptable to adjoining landowners.

The invert level of the lake outlet drain was surveyed in 2007 to provide data to support WRP rule 3.7.4.6.

In 2008 a lake enhancement and wetland restoration project was initiated by the landowners and Waikato Regional Council. A management plan was prepared for the site, which provided recommendations relating to water levels, fencing setbacks, plant pest management, wetland enhancement, new plantings and reducing nutrient loads (Bodmin et al, 2008). Funding of $51,000 was successfully obtained from the Biodiversity Condition Fund to assist with the restoration works between 2009-2012. Works to date include an aerial willow control operation, fencing and planting, and ongoing weed control. Unfortunately, the aerial willow control (using Garlon-360) was unsuccessful, and subsequent ground-based willow control was necessary.

The owners of the lake have covenanted the lake margins with QEII Trust. These areas have been surveyed and are now fully fenced.

Key threats to the lake and its margins include ongoing nutrient enrichment from the lake's large dairy catchment and the ongoing resuspension of internal nutrients due to the lake's shallowness. NIWA assessed nutrient remediation options for the lake that included the construction of an infiltration filter system to treat inflows from the extensive catchment to the north east of the lake (Bodmin et al, 2008).

The lake was electric fished in February 2009 which confirmed the presence of exotic goldfish and a large biomass of catfish in the lake, as well as native eels and bullies (B.Hicks, pers. comm.). NIWA staff reported seeing *Gambusia* and a single koi carp when they visited the lake in February 2008 (Bodmin et al, 2008). It appears that koi carp may be present in small numbers, but their abundance should be confirmed, as this species may represent a major barrier to in-lake restoration.

Pest plant species pose a significant threat to the wetland values at the site –particularly grey willow, royal fern, Japanese honey suckle, arum lily and Chinese privet (Bodmin et al, 2008). Royal fern is of particular concern as it threatens the integrity of the understory due to its ability to form dense colonies and displace small native wetland species.

Options for management and acquisition of information:

- review the minimum lake level with a view to increasing the minimum lake level by an appropriate amount, and include the new level in WRP
- in conjunction with local landowners and the Lake Mangahia Care Group, complete the BCF funded wetland restoration programme;

- support the Lake Mangahia Care Group to take ownership of wetland restoration programme following the completion of funded works (Waipa Accord Group members)
- re-survey lake health indicators
- promote Lake Mangahia as a flagship site for landowner led restoration of peat lakes.

3.6.5 Lake Mangakaware

Depth	4.8 m
TA	Waipa District Council
WRC zone	Waipa
Land tenure	Recreation reserve administered by district council
Lake area	12.9 ha
Estimated catchment area	c. 238ha
Catchment land use	Dairy
Percent native vegetation cover in catchment	0%
Applicable joint agency accord/MOA	Waipa Peat Lakes Accord
Lake level in WRP	✓ 29.1 m (Moturiki datum)
Identified as significant wetland (WRP Rule 3.7.7)	✓
Identified as Priority 1 stock exclusion	✓

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (17)	Lake type (36)	WRC zone (15)
9=	4	4	2
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Mangakaware lies west of Te Awamutu and is situated within a basin of peat that is 1.0 to 2.5m in depth (Waipa District Council, 2007). The lake is managed by Waipa District Council as part of a large (c.48 ha) recreational reserve.

The lake has one major inflow that enters the northern end of the lake under Meadway Road. Several other smaller inflows enter the lake, which drain peat soils and are more heavily peat influenced. It appears that a 15-20 ha portion of the lake's current catchment (that previously drained to Mangaotama Stream) now drains into Lake Mangakaware through the main inflow.

Water quality information has been collected periodically from Lake Mangakaware and the results are summarised in the table below. This data indicates that the lake is extremely nutrient enriched (hypertrophic).

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
1977[a]	1.3	32					
1981[b]	0.5-1.5	86	1153	71		6.0-8.4	3.1
1988[c]	0.9	40	1220	100		6.95	
1988-1994[d]	0.76	71	1750	145		7.07	6.4
1997[e]			1222	220			7.0
2010/2011[f]	0.55	51	1878	213	6.63	6.9	11.13
2011/2012[f]	0.82	148	1582	226	6.53	7.03	8.93
2012/2013[f]	0.57	74	1642	204	6.41		

a Chapman and Boubee (1977)

b Davenport (1981); WVA based on 10 samples taken between January and March 1981

c Page (1988) Mean of two samples taken between December 1987 to March 1988

d Average of 27 samples taken by WRC at Located site 299_1 Lake surface between September 1988 and June 1994

e Thompson and Greenwood (1997) – based on 2 samples collected over a 10 day period during the 1997 summer. Results have been transposed from graphs so are indicative of values

f WRC shallow lake health indicators programme (average of December, March, May samples)

Surveys of submerged vegetation in the lake were carried out in 1991, 2005 and most recently in 2010. Native and exotic species were recorded during the earlier surveys with improved condition and extent of native aquatics observed during the 2005 survey (Edwards et al., 2009). Unfortunately by 2010, these plant communities had declined such that there was insufficient plant cover to generate a Lake SPI score. Whilst plant cover was minimal in 2010, *Nitella* aff. *cristata* and *Potamogeton ochreatus* remained at low density within a narrow zone down to 1m depth, and *Egeria densa* was also present (Edwards et al. 2010).

The district council recreation reserve around the lake is the widest margin in the Waipa District, extending up to 240m from the lake edge (Waipa District Council, 2007). Although it has been leased for grazing and subject to drainage and vegetation clearance in the past, Waipa District Council have realigned fences to retire more of the reserve, and are in the process of retiring and restoring plant communities on the lake margin. The substantial reserve area around Lake Mangakaware presents a considerable opportunity for restoration.

The lake is listed in the WRP as a Priority 1 stock exclusion area, and has been fully fenced to exclude stock since 2005. New fences now exclude stock from a greater area around the lake.

Lake Mangakaware has been a closed game area in the past, but was opened to hunting in 2014 (by Waipa District Council) to alleviate pressure on the Rotopiko lakes. A Hunter Management Plan is being developed by Waipa District Council and the Hamilton Fish & Game Association to ensure that hunting is undertaken in a way that preserves the cultural, landscape and conservation values of the lake in future (Paula Reeves, Waipa District Council *pers. comm.*).

Grey duck, grey teal, NZ shoveler, large black shag, little shag, pied stilt, whitefaced heron and morepork have been recorded from the area, along with other more common species of birds and waterfowl (Waipa District Council 2007).

Four species of native fish are known from Lake Mangakaware - common bully, smelt, and shortfin and longfin eels. Catfish and goldfish are the only pest fish species known from the lake (Wildland Consultants, 2009). The absence of koi carp and rudd is a positive feature that may support the recovery of submerged plants at this lake in future.

Work in the outlet drain in 1997 resulted in substantial lake level reductions. Waipa District Council subsequently installed a rock rubble weir in an attempt to restore minimum water levels to 29.1m, which is the level set in the WRP (Waipa District Council, 2007). Subsequent lake level monitoring indicated that the initial weir height was inadequate. A new minimum level was subsequently proposed and a wooden weir was constructed in June 2007 through a joint project with Waipa District Council. This new weir was set at a height of 29.25 m (Moturiki datum), which should be included in the WRP to reflect the new minimum lake level. The invert level of the lake outlet drain was surveyed in 2007 to provide data to support WRP rule 3.7.4.6 to prevent lake outlet modifications and protect water levels in vulnerable peat lakes.

Waikato Regional Council has monitored lake water levels since June 2003, and a recent review of this data indicates that the weir has effectively maintained water levels at the desired level.

Key existing threats to the lake include ongoing nutrient inputs from the dairy catchment, shrinkage of the low bulk density peat around the lake, and the presence of plant pests, including grey willow and yellow flag iris. As one of the few peat lakes that have retained submerged aquatic plants until recently, and retains remnant populations of some native species, Lake Mangakaware is likely to retain viable seedbanks and may offer real opportunity for restoration.

Waipa Peat Lakes Accord Members have recently initiated a catchment study that involves: (i) monitoring nutrient and sediment inputs to Lake Mangakaware from 3 main drain inflows; and (ii) preparation of whole farm system plans for dairy farms adjoining the lake to identify options for adjoining landowners to improve their environmental and economic performance. Reducing sediment and nutrient losses to the lake is a key focus of these plans.

Waipa District Council prepared a reserve management plan in 2007 for this and other peat lakes in the district. This plan identifies specific activities for Lake Mangakaware, including activities to establish and maintain buffer margins around the lake, set minimum levels and control drainage, control inflows of sediments and contaminants, manage introduced pests, promote recreational use, enhance habitats and protect historic sites (Waipa District Council; 2007). Since then, Waipa District Council has: undertaken (aerial) willow control in January 2009; negotiated fence line changes with leasees that were implemented in 2013, and is planning to construct sediment traps/constructed wetland filters on two lake inflows in 2015. They have also indicated that they intend to close some of the smaller inflowing drains to the lake to allow inflows to filtrate through the vegetated lake margin.

Reducing the external nutrient load and undertaking surveillance for new aquatic plant pests and exotic fish species are also high priorities from both a water quality and biodiversity perspective.

Options for future management and acquisition of information:

- minimum lake level of 29.25m (Moturiki datum) to be recorded in the WRP
- Work with Waipa District Council to consider options to further raise the lake level to maximise wetland habitat around the lake margin
- continue to work with adjacent landowners to improve land management practices
- support Waipa District Council to undertake weed control and planting on the lake margins and inflowing water ways
- support Waipa District Council to improve the riparian management of inflowing waterways/drains
- encourage and support Waipa District Council to retire further areas of reserve land from leased grazing.
- carry out regular submerged plant surveys (Lake SPI).
- survey fish populations.
- continue regular monitoring of water quality and lake health indicators.

3.6.6 Lake Maratoto

Depth	7.1 m
TA	Waipa District Council
WRC zone	Central Waikato
Land tenure	Private land – part QEII covenant
Lake area	18 ha
Estimated catchment area	Previously estimated at c. 168 ha Estimated at c.88 ha in 2013[10]
Catchment land use	Dairy
Percent native vegetation cover in catchment	25.07%
Applicable joint agency accord/MOA	Waipa Peat Lakes Accord
Lake level in WRP	✓ 51.3 m (Moturiki datum)
Identified as significant wetland (WRP Rule 3.7.7)	✓
Identified as Priority 1 STOCK exclusion	✓

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (17)	Lake type (36)	WRC zone (7)
2	1	1	1
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Maratoto is located around 13km south of Hamilton City and lies on the outer fringe of the Rukuhia Peat Bog. The lake has Rukuhia peat soils on the western side and Kaipaki soils to the east and is strongly acid and peat stained (Champion et al; 1993).

[10] Golder Associates (2013)

Waikato Regional Council has been monitoring water quality in Lake Maratoto at regular (c.monthly) intervals since 2002. Between 2002-2008, concentrations of TN increased at an average rate of about 9% per annum, and Chl *a* concentrations by an average of about 14% per annum. There were no comparable changes in TP over this period. Chlorophyll a (an indicator of phytoplankton biomass) increased particularly sharply from 2006-2008. As Lake Maratoto appears to be phosphorus limited, it may be that increasing TN is of less ecological significance than TP (Bill Vant, 2008). Recent analysis of data collected between 2006 and 2010 indicates that there has been no change in trophic state in Lake Maratoto (WRC 2012).

Lake Maratoto is the only Waipa peat lake with water that has a pH lower than 7 indicating that the lake retains a strong (acidic) peat influence. A summary of water quality data is presented in the table below.

	Mean SD (m)	**Mean Chl *a* ($mg\ m^{-3}$)**	**Mean TN ($mg\ m^{-3}$)**	**Mean TP ($mg\ m^{-3}$)**	**Estimated TLI**	**pH**	**Turbidity (NTU)**
1981[a]	0.3-0.6	36	1239	47		4.8-5.8	1.3
1988[b]	0.5	33	2110	65		5.5	
1997[c]			984	10			7.0
2003-2007[d]	1.0	32	1400	29			
2006-2010[e]					5.4		
2007/2008[f]	0.9	40.5	1953	32	5.6	6.25	3.2
2008/2009[g]	0.96	11	2276	25	5.17	5.63	2.2
2009/2010[g]	0.75	14	1756	18	5.13	5.4	1.9
2012/2013[g]	0.46	12.3	1493	33	5.36		

a Davenport (1981); WVA based on 10 samples taken between January and March 1981

b Page (1988) Mean of two samples taken between December 1987 to March 1988 – surface sample figures have been used for TP and TN

c Thompson and Greenwood (1997) – based on 2 samples collected over a 10 day period during the 1997 summer. Results have been transposed from graphs so are indicative of values

d Waikato Regional Council data reported in Hamilton et al (2009)

e 2006-2010 Waikato Regional Council – Shallow lakes water quality monitoring programme – monthly samples. Data taken from Nutrient enrichment of shallow lakes State of the Environment Indicator: WRC (2012)

f WRC shallow lake health indicators programme (December/March) Neilson & Hamer 2008

g WRC shallow lake health indicators programme (average of December, March, May samples)

Analysis of rotifer communities in the lake over the summer of 2007/08 provided a rotifer inferred TLI of 3.43 (mesotrophic) (Duggan, 2008). Given the heavy peat staining of the water of Lake Maratoto, the rotifer inferred TLI may be a more accurate reflection of the lake health than the standard TLI calculation that infers that the lake is supertrophic (Waikato Regional Council, unpublished data).

Submerged plant surveys were carried out at the lake in 1992 and 2009. On both occasions submerged vegetation was absent (Edwards et al., 2009) which may reflect the natural condition of these types of dystrophic lakes where light penetration is limited by heavy peat staining.

Lake Maratoto is currently fully fenced to exclude stock, although approximately 250m of fencing on the north-western margin may require upgrading. Approximately 47 ha of the lake bed and surrounding margin is subject to a QEII covenant. This includes a (c. 22 ha) stand of mature manuka on the western side of the lake and a 50 m fenced margin around the southern and eastern sides of the lake. A newly constructed fence on the north-eastern margin excludes stock from a 10-40 m wide strip of uncovenanted lake margin.

Until recently much of the southern and eastern lake margins were dominated by gorse. Waikato Regional Council has been working with the landowners to carry out plant pest control and native planting along these margins. Funding of $49,000 was successfully obtained from the Waikato Catchment Ecological Enhancement Trust (WCEET) in 2009 to assist with the project over a 3 year timeframe.

In addition to this work, and as part of a subdivision consent relating to land at the southern end of the lake, the landowners are also required to develop and implement a restoration plan for the lake's wetland margins. Several plans have been prepared for the landowners (Kessels 2007, Dean 2011a & Bennett 2014) but have not yet been implemented.

A minimum lake level of 51.3m (Moturiki datum) has been set for Lake Maratoto (s. 3.2.4.7 of the WRP), and a wooden v notch weir was constructed in the lake outlet in March 2004 at this height. This weir replaced a concrete vertical slot weir that had previously been constructed by the landowner at least c.10 years earlier. Whilst a minimum water level was set at 51.3m, there were concerns about the adequacy of this level to sustain the ecological values of the lake and associated wetlands.

Unfortunately, the weir has failed to maintain lake levels at or above 51.3m, and there are concerns about the long-term sustainability of the lake and adjoining wetlands if water levels continue to decline. The sources and mechanics of water loss are presently unknown, but recent surveys have confirmed the accuracy of the water level monitoring records that WRC holds for the lake (i.e. the accuracy of benchmark and ESG heights), and established that the weir remains at its constructed height of 51.3m (Harrison Grierson 2011b).

Waikato Regional Council has commissioned a hydrological study of Lake Maratoto (including preparation of a water balance) and has subsequently installed a number of piezometers around the lake margin to develop a better understanding of groundwater levels and movement. It is anticipated that this information will support a future proposal to modify the weir in future to increase its effectiveness, and/or seek an alternative (higher) minimum lake level to sustain and improve the ecological values of the lake.

The lake supports a number of threatened species and is considered to have the most intact peat bog vegetation of all of the Waipa peat lakes (Wildland Consultants 2009). Recent studies indicate that the condition and quality of the manuka wetland has declined as a result of lower lake and groundwater levels and weed invasion (Clarkson 2014). Options to restore and improve this wetland are currently being assessed, but will also be considered in future lake level setting processes.

Major threats include drainage and peat shrinkage, nutrient inputs from surrounding land use, submerged aquatic weed incursion, pest fish incursion and removal of marginal vegetation.

Options for management and acquisition of information:

- complete a groundwater study at Lake Maratoto, and identify options to (i) effectively maintain the lake level at the consented height of 51.3m (ii) establish a more ecologically appropriate minimum lake level for the lake and associated vegetation.
- work with landowners to establish an ecologically appropriate minimum water level for the lake by June 2015
- complete current WCEET funded wetland enhancement project and work with landowners to advocate ongoing weed and animal pest control at the site.
- work with Waipa District Council to encourage landowners at the northern end of the lake to formally protect and fence their lake margin and inflowing drains.
- support Waipa District Council and landowners where possible to implement the Restoration Management Plan for Lake Maratoto (as part of the subdivision requirements)
- encourage QEII to improve the management of the covenanted area at Lake Maratoto
- survey fish populations
- continue regular monitoring of water quality and lake health indicators.

3.6.7 Lake Milicich

Depth	2.3 m
TA	Waipa District Council
WRC zone	Waipa
Land tenure	Private
Lake area	2.2 ha
Estimated catchment area	54 ha
Catchment land use	Dairy/horticulture
Percent native vegetation cover in catchment	4.66%
Applicable joint agency accord/MOA	Waipa Peat Lakes Accord
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (17)	Lake type (36)	WRC zone (15)
17	7	8	5
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Milicich is a c.2 ha peat lake situated at Rukuhia in the Waipa district. The margin and bed of this lake is privately owned by several landowners.

Waikato Regional Council staff accompanied Waipa District Council staff on a visit to the Milicich property in May 2008 to discuss subdivision options. They reported that the lake was surrounded by a thin margin of grey willow with an understorey of swamp

coprosma, kahikatea and flax, with areas of sphagnum moss. Bands of raupo and kuta (*Eleocharis sphacelata*) occurred in the littoral zone.

The lake receives water from 4 inflows that are located to the north, east and south of the lake. The lake outlet drains from the south western side of the lake into a tributary of the Mangaotama Stream and then to the Waipa River. The lake outlet is cut through a clay ridge approximately 40m from the lake, which acts as control on minimum lake water levels.

Access to Lake Milicich has been restricted, so Waikato Regional Council holds only limited water quality information for the lake. The lake was visited during the 2008/09 and 2009/10 as part of WRC's shallow lake health indicator programme. This information is presented in the table below. The most recent data indicates that the lake has extremely high levels of nutrient enrichment and is hypertrophic. However, there is a considerable difference between the water quality data collected in 08/09 and 09/10, which may be an indication of underlying variability in lake condition or reflect deterioration. Further investigation and long term data collection would be required to determine this.

	Mean SD (m)	**Mean Chl *a* ($mg\ m^{-3}$)**	**Mean TN ($mg\ m^{-3}$)**	**Mean TP ($mg\ m^{-3}$)**	**Estimated TLI**	**pH**	**Turbidity (NTU)**
1977[a]	0.5	16.4				5.7	
1988[b]	0.63	57.9	1490	60		5.6	
1997[c]			2573	280			9.0
2008/2009[d]	1.20	25	1156	61.3	5.42	7.46	6.16
2009/2010[d]	0.7	192	2576	142	6.65	7.16	7.46

a Chapman and Boubee (1977)

b Page (1988) Mean of two samples taken between December 1987 to March 1988 – surface sample figures have been used for TP and TN

c Thompson and Greenwood (1997) based on 2 samples collected over a 10 day period during the 1997 summer. Results have been transposed from graphs so are indicative values only

d WRC shallow lake health indicators programme (average of December, March, May samples)

Staff reported that the lake appeared to have better water clarity at the time of their visit (May 2008) than similarly sized peat lakes, and that the landowner reported that the lake did not experience algal blooms (Neilson & Hamer, 2008).

Lake Milicich was surveyed for aquatic plants for the first time in 2009. No submerged aquatic plants were found, although they would have occurred in the lake historically. Floating fragments of the invasive bladderwort *Utricularia gibba* were the only plants observed during these surveys, although they were present at insufficient densities to generate a Lake SPI score. The impact of *U. gibba* at this and other lakes is unknown (Edwards et al., 2009), but control is not recommended or considered practical given the likelihood of it being dispersed by wildfowl (Mary de Winton, *pers. comm.).*

The lake is not listed as a priority stock exclusion site in the WRP, although it does appear to be fenced to exclude stock. When the lake was visited in 2008, a 5 wire electric fence was in place around the vegetated lake margin. The fence may require upgrading in some sections, and came very close to the lake edge in places. Winter lake levels extended beyond the fence, and land immediately outside of the fence was extremely wet and pugged.

The lake has been in the same private ownership for many decades, but one property was recently sold and may be vulnerable to new drainage.

The outlet of Lake Milicich (as for other lakes) is defined as a modified water course under the WRP and as such is unable to be disturbed without consent (under rule 4.3.4.4.). To establish baseline information and protect the lake from future drainage, the invert level of the outlet drain was surveyed by WRC in June 2008. The survey results indicate that the outlet drain cuts through a clay sill located to the south-west of the lake approximately 40m along the outlet. This sill (at a height of 40.74 m) currently controls the minimum lake level and should be included in the WRP, since Lake Milicich is listed under section 3.7.4.5 for a lake level setting exercise.

The major threats to the lake and surrounding wetland include new drainage, ongoing nutrient inputs from surrounding agricultural land and increasing dominance of invasive plant species (aquatic and terrestrial). The status of fish populations in the lake are unknown. Surveys in 1987/88 did not locate any introduced species (Page, 1988), although *Gambusia* were observed during a site visit in 2008, and a previous landowner recalled seeing catfish and goldfish in the lake, but not koi carp.

Options for management and acquisition of information:

- minimum lake level of 40.74m (Moturiki datum) to be included in the WRP to reflect the level of the clay sill at the lake outlet that controls the lake height;
- advocate for the inclusion of Lake Milicich in the upcoming WRP reviews as a priority site for stock exclusion;
- advocate for the inclusion of Lake Milicich as a wetland of significance in the upcoming WRP review process to protect against future drainage of these areas.
- work with Waipa DC to encourage the landowners (including funding where possible) to upgrade and realign fences to establish a wider margin around the entire lake.
- provide assistance to landowners for pest control and revegetation of the lake margin (particularly if the large margin is extended)
- survey fish populations
- revisit Lake Milicich as part of the shallow lake health indicators programme to monitor water quality and lake health indicators.

3.6.8 Lake Ngaroto

Depth	c.4.0 m (max), 2.0m (average)
TA	Waipa District Council
WRC zone	Waipa
Land tenure	Recreation reserve administered by District Council
Lake area	108 ha
Estimated catchment area	1846 ha
Catchment land use	Dairy
Percent native vegetation cover in catchment	0.51%
Applicable joint agency accord/MOA	Waipa Peat Lakes Accord
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✓
Identified as Priority 1 Stock Exclusion	✓

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (17)	Lake type (36)	WRC zone (15)
19=	8	10=	6
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Ngaroto is the largest of the peat lakes in the Waikato region. The lake is part of a 149.1ha recreation reserve that is managed by Waipa District Council via a reserve management plan to protect and maintain its important recreational, cultural and natural values. A 13 ha paper road surrounds the lake which has been included within the reserve fencing

Lake Ngaroto was formed some 19,000 years ago, and is thought to have been about 220ha in size (open water/surface area) at the turn of the 20th century. This area was reduced to 90ha by 1960 through drainage activities that were undertaken to reclaim the lake and its margins for agricultural use. Today, Lake Ngaroto occupies a total areas of approximately 150ha, with an open water area of c. 90ha, and a scrub and marginal wetland are of c. 60ha (BCD 2014).

Lake Ngaroto receives water from 3 major inlets as well as several minor drains. The three main subcatchments are to the south (755ha), east (620ha), and west (300 ha) of the lake. The most significant inflow enters Lake Ngaroto via Lake Ngaroto-iti, which provides approximately one third of the inflows to the lake and the highest relative nutrient inputs (BCD 2014).

The lake outlet is situated at the northern end of the lake. Water exits the lake into the Mangaotama Stream and travels some 12 km before it reaches the Waipa River.

Lake Ngaroto is highly significant to Maori, as the site of many important historical and cultural events, including the Battle of Hingakaka. Six pa sites are located in close proximity to the lake, including 3 swamp pa (Waipa DC 2009).

Lake Ngaroto is also subject to high levels of recreational use, including contact recreation, and has a number of facilities and infrastructure (wharf, boat ramps, toilets, board walks and public walking tracks) to facilitate public enjoyment. Visitor numbers are estimated to be in the order of 20-25,000 per annum (NZ Landcare Trust 2011). Visitation is expected to rise significantly when the cycling track around the lake is completed in 2015.

Water quality has been measured periodically in Lake Ngaroto since the 1970's. Since 2009, Waipa District Council has collected water quality information via an automatic monitoring buoy[11] that is installed and serviced by Waikato University.
Water quality information held by WRC is summarised in the table below. It confirms that the lake has very high levels of nutrient enrichment (ie is hypertrophic), high levels of turbidity, and poor transparency. The lake also suffers recurrent algal blooms that are dominated by *Microcystis* spp., a toxic blue-green algae. During these blooms, Lake Ngaroto is closed to contact recreation.

The automatic monitoring buoy has recently detected a trend of increasing anoxic events at the lake bed during the summer months following stratification, which is unusual for such a large and shallow lake.

	Mean SD (m)	**Mean Chl *a* ($mg\ m^{-3}$)**	**Mean TN ($mg\ m^{-3}$)**	**Mean TP ($mg\ m^{-3}$)**	**Estimated TLI**	**pH**	**Turbidity (NTU)**
1977[a]	1.2	11.4					
1981[b]	0.3-0.6	86	1261	84		6.6-8.7	6.3
1988[c]	0.48	192	1990	110		8.0	
1992-1994[d]	0.57	34	1366	84		7.5	11
1992-1994[e]	0.6	31	1627	81		7.5	10.6
1995-2001[f]	0.59	65	1900	118	6.34		
2006-2008[g]	0.7	66	2300	130			
2009[h]	0.40		1200	130			
2011/2012[i]	0.36	53	1885	126	6.29	7.13	26
2012/2013[i]	0.35	127	2988	165	6.81		

a Chapman and Boubee (1977)

b Davenport (1981); WVA based on 10 samples taken between January and March 1981

c Page (1988) Mean of two samples taken between December 1987 to March 1988 – surface sample figures have been used for TP and only bottom sample figures available for TN

d Average of 20 samples taken by WRC at Located site 303_4 Lake centre surface between October 1992 and June 1994

e Average of 27 samples taken by WRC at Located site 303_7 Lake south surface between October 1992 and June 1994

f 1995-2001 – Average values for samples taken October 1995-2001. Barnes (2002a) – WRC data

g Data presented by Hamilton et al. 2010 - water quality for 2006-08; TLI for 2002

h Waikato University sampling results 28 May 2009 – B. Hicks pers. comm.

[11] Water temperature, dissolved oxygen, chlorophyll a and phycocyanin, and meteorological measurements taken every 15minutes

The lake has been surveyed for submerged plants on at least five occasions over the last 30 years. These surveys have documented the decline and loss of native species, along with the dominance and subsequent collapse of introduced species in the lake. The two most recent surveys, undertaken in 1992 and 2003, failed to locate any evidence of submerged plants (Edwards et al., 2009).

Twenty nine (29) species of wetland birds have been recorded from Lake Ngaroto, although bird numbers have been considerably reduced from historical levels (Wildland Consultants Ltd 2008a, Waipa District Council 2009). Several species of special conservation status are known from Lake Ngaroto including one 'nationally critical' species (white heron *Egretta alba*), two 'nationally endangered' species (Australasian bittern *Botaurus poiciloptilus* and grey duck *Anus platyrhynchos*) and one 'nationally vulnerable' species (Caspian tern *Sterna caspia*). Important species found occasionally in open water include the New Zealand dabchick (*Poliocephalus rufopectus*), New Zealand scaup (*Aythya novaeseelandiae*), black shag (*Phalocrocorax carbo*), and little black shag (*P. melanoleucos*)

A number of species are found feeding, nesting and loafing around the margins of the lake including black swan (*Cygnus atratua*), Canada geese (*Branta canadensis*), mallard duck (*Anus platyrhynchos*), grey teal (*A. gracilis*), and shoveler (*A. rhynchotis vargiegata*), banded rail (not recently), spotless crake, and marsh crake. The white heron, white faced heron (*Ardea novaehollandiae*); cattle egret (*Bubulus ibis*), pied stilt (*Himantopus himantopus*); spur winged plover (*Vanellus miles*), and occasional South Island pied oyster catcher (*Haematopus ostralegus*) are found feeding opportunistically around the margins and meadows.

While some species (white heron and Caspian tern) may only be occasional visitors, Lake Ngaroto is an important part of wetland networks for many species such as the Australasian bittern. Numbers of many species will have declined over the years due to low water clarity and changes to the wetlands, macrophytes, and margins which may have affected these networks.

The effects of the current water level regime probably affect water bird communities more significantly than any other aspect of the lake ecology. This is primarily due to the timing of the artificial raising of the water levels. Raising the lake water level by ~ 20 cm half way through the critical breeding period (August-November), increases the risk of nest inundation and is likely to have affected breeding success of species that nest at the lake margins (Wildland Consultants 2010b).

Historically Lake Ngaroto would have provided habitat for a diverse array of indigenous fish species including eels, galaxiids, grey mullet (*Mugil cephalus)*, smelt (*Retropinna retropinna*), bully, and possibly lamprey (*Geotria australis)* (Waipa District Council 2009).

A comprehensive fish survey carried out in 2001 recorded nine species, four native species and five introduced species (Hicks *et al*. 2001). The most common native species was the short-finned eel (*Anguilla australis)* with common bullies (*Gobiomorphus cotidianus*), a few longfin eels (*Anguilla dieffenbachii*) and a single common smelt. Over 70% of the catch was the brown bullhead catfish (*Ictalurus nebulosus*) followed by rudd (*Scardinius erythrophthalmus*), goldfish (*Carassius auratus*) and a single mosquito fish (*Gambusia affinis*) and koi carp (*Cyprinus carpio*) were caught.

The fish population was resurveyed in early 2009 and was found to be less diverse than the 2001 surveys with no smelt or longfin eels captured. Seventy percent of the total catch in 2001 was catfish but in the 2009 sampling they only contributed 5% of total

catch. Goldfish contributed 27% of the catch, (1% in 2001), rudd 20% (similar to earlier survey), and koi carp and mosquito fish 10 and 15% respectively (only single specimens recorded earlier). Unfortunately, it is difficult to draw firm conclusions about these results as different methods were used for each of these surveys. However, the low variety of native fish in Lake Ngaroto is likely to be the result of poor habitat quality (e.g. lack of macrophytes, hyper-eutrophic water quality), commercial fishing of eels, and predatory pressures and competition from exotic fish species (Waipa District Council 2008). Until recently there was no fish passage at the weir which may have contributed to the low numbers of common smelt.

The margins of Lake Ngaroto are a mix of exotic and native plant communities, including raupo reedland, willow, and swamp meadow wetlands. Manuka scrubland occurs in drier areas, largely as a result of an active planting programme that began in from the mid 1990s. Unfortunately much of the manuka is reaching the end of its lifespan. With funding support from the Waikato River Clean Up Trust, Waipa District Council staff have initiated programmes to undertake and enhance riparian plantings at Lake Ngaroto and undertake fish reduction programmes.

The lake is fully fenced with margins ranging from about 30 - 200 m in width. While most of the reserve area is included within the fenced boundaries, small areas of the reserve continue to be farmed (BCD 2014).

The lake is listed in 3.7.4.5 of the WRP as requiring a minimum lake level to be set. The outlet drain has been surveyed by Waipa District Council so there is data available to support the implementation of Rule 3.7.4.6.

A reinforced concrete weir structure with a steel radial control gate located at the outlet of Lake Ngaroto currently controls lake water levels. The height of the gate has been managed to lower water levels over winter and increase summer water levels. This regime has served to benefit adjacent farmers and recreational users, but has removed natural seasonal fluctuations and contributed to the ecological deterioration of Lake Ngaroto (Greenwood, 2001).

The resource consent for the operation of the current weir expired in October 2010. Since that time, Waipa District Council has gathered information and assessed options and implications of different weir designs and heights. Waikato Regional Council has been recording water levels in Lake Ngaroto since November 2003 and this data is provided to Waipa district to assist in this decision making.

Waipa District Council has recently sought approval to install a new timber weir to establish a year-round minimum water level (of 34.34m Moturiki datum) for Lake Ngaroto. As part of this proposal, they have also sought to divert the inflow from Lake Ngaroto-iti to the Mangaotama Stream, in order to reduce flooding on adjoining properties during winter. It is possible that the diversion may help reduce sediment and nutrient inputs to Lake Ngaroto.

New Zealand Landcare Trust has undertaken a three year project around Lake Ngaroto (2012-2015), with the objective of improving the overall health of the catchment and slowing the decline of the lake's water quality. Eight whole farm plans and a catchment action plan have been developed as part of this project. Tools and opportunities to reduce sediment and nutrient inputs to Lake Ngaroto have been considered in the catchment action plan which identifies five priority sites for construction of silt traps/infiltration wetlands (Landcare Trust 2014).

Reserve management plans have been prepared for the Lake Ngaroto Recreation Reserve since 1979 following initial studies by staff and students at Waikato University[12] that were commissioned by Waipa County Council. These studies identified restoration and management options and collected important baseline information about the condition of the lakes.

Between 1995 and 2002, a restoration programme was implemented by Waipa District Council that involved:

- realignment and fencing of a new legal boundary
- consideration of inflow treatment to reduce sediment and nutrient inputs to Lake Ngaroto – which involved the installation of silt traps in 1999
- progressive removal of willow species from the reserve
- restoration plantings around the lake margin
  (as described by Greenwood 2001).

The most recent reserve management plan was prepared in 2009. It outlines the resources and condition of the lake and reserve, its historical and current uses, management issues, and policies for future management of the lake and surrounding reserve.

The 2009 reserve management plan identifies the following management objectives:

- improvement of the quality of water in Lake Ngaroto to ensure ongoing water based recreation opportunities are available to users and visitors;
- ensuring sufficient water depth to enable ongoing competitive safe recreational sailing of yachts;
- ensuring sufficient length of water course is available to enable competitive rowing, waka paddling and canoeing;
- protecting and enhancing the indigenous plant and animal populations;
- maintaining the ecological processes that will ensure the survival of the Reserve's indigenous biota;
- securing and protecting the cultural and historic sites and features around the margin of the lake;
- recognising the spiritual importance of the Lake to iwi;
- promoting Lake Ngaroto as an interesting and enjoyable destination;
- maintaining the infrastructure in the reserve (tracks, boat ramps etc).

The management issues identified in the plan are:

- improving the reserve boundaries – boundary alignment, protection of wetland areas and stock proof capacities
- lake level management
- management of the marginal zones to improve biodiversity and habitat availability
- management of nutrient inputs
- investigation of nutrient input treatment options such as constructed wetlands
- securing and protecting the remaining Swamp Pa
- maintaining and improving recreation use opportunities and experience
- animal and plant pest control to improve biodiversity.

The reserve plan is expected to be reviewed again in the near future (Waipa District Council; 2009).

Options for management and acquisition of information:

- resurvey lake health indicators

[12] particularly M.A. Chapman and J. Boubee

- support Waipa District Council as appropriate to implement its management plan for the lake
- provide support to Waipa District Council where possible to monitor the condition of Lake Ngaroto and the effectiveness of management actions
- support catchment initiatives to reduce sediment and nutrient inputs to the lake.

3.6.9 Lake Ngarotoiti

Depth	1.0 m
TA	Waipa District Council
WRC zone	Waipa
Land tenure	Wildlife management reserve administered by the Department of Conservation
Lake area	3.4 ha
Estimated catchment area	504 ha
Catchment land use	Dairy
Percent native vegetation cover in catchment	0.45%
Applicable joint agency accord/MOA	Waipa Peat Lakes Accord
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✓
Identified as Priority 1 stock exclusion	✓

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (17)	Lake type (36)	WRC zone (15)
51	16	30	14
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Ngarotoiti is a small lake with five inlet drains delivering water and nutrients from a c.500ha dairy catchment. This by far the highest ratio of lake volume to catchment area of any peat lake in the Waipa district. The lake forms part of the wider Lake Ngaroto catchment.

The lake has been subject to drainage, and is now very shallow. An outlet has been cut through deep clay and Lake Ngarotoiti currently discharges into Lake Ngaroto. Waipa District Council have recently sought consent to divert the outlet of Lake Ngarotoiti directly to the Mangaotama Stream in future in order to reduce flooding effects of winter lake levels on adjacent properties (BCD 2014).

Water quality information has been collected several times in the last 30 years and is summarised in the table below. These results indicate that the lake is extremely nutrient enriched (i.e. hypertrophic). No recent water quality information is held by Waikato Regional Council.

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
1977[a]	0.25	155					
1988[b]	0.15	493	6150	530		9.4	
1997[c]			3907	550			48

a Chapman and Boubee (1977)
b Page (1988) Mean of two samples taken between December 1987 to March 1988 – surface sample figures have been used for TP and TN
c Thompson and Greenwood (1997) based on 2 samples collected over a 10 day period during the 1997 summer. Results have been transposed from graphs so are indicative of values

Dairy shed effluent has previously been discharged directly into inflows of Lake Ngarotoiti, but these have largely transitioned to land-based treatment systems now. Despite these improvements, the lake continues to be extremely eutrophic.

The lake does not support any submerged aquatic plants so no Lake SPI surveys have been undertaken. As well as water quality limitations, plant growth is likely to have been further prevented by the dense populations of koi carp that occur in the lake.

Thompson and Greenwood (1997) described the lake as being perhaps the most neglected and abused of all the lakes in Waipa district. At that time the lake was completely unfenced with stock accessing the entire lake margin. The lake is identified in the WRP as a Priority 1 waterbody for stock exclusion, and is now fully fenced. On the western, northern and eastern sides of the lake, the fence is located on the DOC reserve boundary which is some 15-30 m from the lake edge in summer but may be inundated in winter. Waipa District Council recently acquired an additional 20m strip (an esplanade reserve) on the southern and northern sides of the lake, and has realigned the southern fence to take in this area. The northern fence will be will be constructed in 2015.

Waipa District Council has had the outlet drain of Lake Ngarotoiti surveyed as part of their studies on Lake Ngaroto. The height of the invert of the culvert going under Lake Road (34.76 m) could therefore be included in the WRP to establish the existing minimum lake level for Lake Ngarotoiti.

Lake Ngarotoiti is in very poor condition and future management is likely to be focused on habitat enhancement and possible water treatment options treating water from the catchment prior to it entering Lake Ngaroto downstream. The Ngaroto-iti Lake Action Group was recently formed to lead restoration action at this lake. They have undertaken animal pest control and pest fish control at the lake since 2011 and were recently granted funding from the Waipa District Heritage Fund to control willows and replant the lake margin in 2014/15.

Options for management and acquisition of information:

- height of Lake Road culvert to be listed in the WRP as the minimum lake level.
- work with landowners and other stakeholders to ensure that dairy shed effluent disposal in the catchment is consistent with best practice
- support Waipa District Council to obtain additional esplanade reserve along the eastern and northern margins of the lake.
- contribute where possible to funding for planting within reserve areas through Catchment New Works/Clean Streams programmes.
- sample lake health indicators.

3.6.10 Lake Pataka

Depth	5.0 m
TA	Waipa District Council
WRC zone	Waipa
Land tenure	Private
Lake area	4.6 ha
Estimated catchment area	55 ha
Catchment land use	Dairy
Percent native vegetation cover in catchment	13.44%
Applicable joint agency accord/MOA	Waipa Peat Lakes Accord
Lake level in WRP	✓ RL 43.01 (Moturiki datum) - to be introduced to the WRP by variation
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (17)	Lake type (36)	WRC zone (15)
30	11	16	10
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Pataka is a small privately owned peat lake that is situated at the edge of the Rukuhia peat bog and is hydrologically linked to the adjacent Lake Posa. Peat depths increase rapidly to the east and south of the lake. (Thompson & Greenwood; 1997).

Lake Pataka has been visited and sampled on several occasions. The water quality results (shown in the table below) indicate that the lake has been extremely nutrient enriched (i.e. hypertrophic). Phosphorus levels were extremely high in 1997, which may have resulted from fertiliser additions to adjacent maize or the exposure of vivianite deposits through extensive drainage (Thompson & Greenwood 1997).

Unfortunately, Waikato Regional Council holds no recent water quality information for Lake Pataka.

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
1977[a]	0.5	18					
1988[b]	0.475	180	1070	480		6.7	
1997[c]			2613	1950			9.0

a Chapman and Boubee (1977)

b Page (1988) Mean of two samples taken between December 1987 to March 1988 – surface sample figures have been used for TP and TN

c Thompson and Greenwood (1997) based on 2 samples collected over a 10 day period during

the 1997 summer. Results have been transposed from graphs so are indicative of values

Surveys for submerged vegetation were carried out in 1977 (Chapman & Boubee, 1977), and 1992 (Champion et al., 1993), and a Lake SPI assessment was undertaken in 2007 (Edwards et al, 2009). The latter two surveys noted the presence of native charophytes though these plants did not occur in sufficient not in density to generate a Lake SPI score.

When last visited by Waikato Regional Council staff, Lake Pataka was surrounded by a narrow (10-15 m wide), fully fenced vegetated margin that was fully encircled by a farm race. Waikato Regional Council staff undertook willow control and planted native species within the lake margin during 2007/08 in conjunction with previous landowners.

Lake Pataka has been subject to substantial amounts of drainage in the past, including lake level reductions of around 1 metre in the mid 1990s. As a result Lakes Posa & Pataka are identified in the WRP for lake level setting processes.

In 2008, the surrounding property was purchased for dairy conversion. The new landowners subsequently carried out substantial further drainage works in close proximity to the lake. Because of concerns about the vulnerability of the lake to further drainage, the lake, outlet drains and existing culverts were surveyed in December 2008. The invert of the culvert (43.01 RL) will be proposed as the minimum lake level. The length of the outlet through to neighbouring Lake Posa has also been surveyed in order to provide baseline data to assess the impacts of any future unauthorised work.

Given the recent conversion to dairy farming in the catchment of Lake Pataka, the lake is considered to be particularly vulnerable to further deterioration in water quality. Unfortunately, with the change of land ownership, ongoing maintenance of the weed control and planting programmes within the lake margin are not guaranteed. Therefore plant pests – in particular grey willow and blackberry – are likely to pose an ongoing threat. There are currently a number of practices close to the lake (for example storage of lime close to the margin, and the location of farm race) which are far from ideal and highlight the need for an examination of the Regional Plan rules protecting lakes.

Little is known of the fish and bird communities in Lake Pataka, although the lake is known to be used for duck hunting.

Options for management and acquisition of information:

- introduce a minimum lake level of 43.01 (Moturiki datum) to the WRP
- advocate for the inclusion of Lake Pataka as a wetland of significance to be included in any review of the drainage rules in the upcoming WRP review process
- assess the feasibility and hydrological implications of diverting the main inflowing drain from the east around to the outlet of Lake Posa.
- work with landowners in the lake catchment to encourage best management practices on farm and ongoing weed control and maintenance of plantings.
- survey lake health indicators.

3.6.11 Lake Posa (Lake Pataka South)

Depth	4.0 m
TA	Waipa District Council
WRC zone	Waipa
Land tenure	Private
Lake area	2.05 ha
Estimated catchment area	95 ha
Catchment land use	Dairy
Percent native vegetation cover in catchment	9.84%
Applicable joint agency accord/MOA	Waipa Peat Lakes Accord
Lake level in WRP	✓ RL 42.13 (Moturiki datum) - to be introduced to the WRP by variation
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (17)	Lake type (36)	WRC zone (15)
28=	9=	14=	8=
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Posa is a small privately owned peat lake that is embedded in deep peat at the edge of the Rukuhia peat bog. Lake Posa receives water from five inflows, including the outlet of adjoining Lake Pataka. (Thompson & Greenwood 1997).

Lake Posa has been visited and sampled on several occasions in the past as part of studies undertaken for Waipa District Council. Waikato Regional Council does not hold any recent water quality information for the lake.

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
1977[a]	0.4	3.3					
1988[b]	0.6	54.4	1470	390		6.4	
1997[c]			1458	900			5.0

a Chapman and Boubee (1977)

b Page (1988) Mean of two samples taken between December 1987 to March 1988 – surface sample figures have been used for TP and TN

c Thompson and Greenwood (1997) based on 2 samples collected over a 10 day period during the 1997 summer. Results have been transposed from graphs so are indicative of values

Surveys for submerged vegetation were carried out in 1977 and 1992 (Champion et al., 1993) and a Lake SPI assessment was completed in 2007 (Edwards et al, 2009). No

submerged plant species were found in any surveys, with the exception of a single plant found in 1992. Edwards et al. (2009) concluded that a substantial increase in water clarity of the lake would be necessary for submerged vegetation to develop at the lake.

Minimal marginal vegetation was reported to remain around the lake margin in 1997 (Thompson & Greenwood; 1997). In 2007 Waikato Regional Council staff worked with landowners on the property at the southern end of the lake to fence and plant a 10-20 m wide strip of lake margin. At that time, the lake was mostly fenced, except for the margin on the eastern side of the northern property. Subsequent visits to the southern property indicate that the fence has not been maintained to a stock-proof standard so it is likely that stock will have regained access to the lake margins.

In 2008 the property adjoining the northern lake end was purchased for dairy conversion and substantial new drainage carried out within 200 m of the lake. The lake has been identified in the WRP as requiring a minimum level. Recording water levels at the lake has proven to be problematic and following concerns about the vulnerability of the lake to water level lowering, the outlet was surveyed in December 2008. The critical level was determined to be situated at location of a collapsed culvert. This level (42.13 RL) will be proposed as the minimum lake level for inclusion in the WRP in future. A 200m length of the outlet, from the lake edge south was also surveyed in order to provide baseline data in case of any future unauthorised works.

Following the recent conversion of one of the two properties adjoining the lake, the catchment is now entirely used for dairy farming. As for Lake Pataka, some of the associated practices – such as the location of the dairy shed and farm effluent ponds close to the lake margin – highlight the lack of appropriate protection for lakes under the Regional Plan.

Options for management and acquisition of information:

- introduce a minimum lake level of 42.13m (Moturiki datum) to the WRP
- advocate for the inclusion of Lake Posa as a wetland of significance to be included in any review of the drainage rules in the upcoming WRP review process
- assess the feasibility and hydrological implications of diverting the main inflowing drain from the east of Lake Pataka around to the outlet of Lake Posa.
- work with landowners in the lake catchment to encourage best management practices on farm and ongoing weed control and maintenance of plantings.
- survey lake health indicators of Lake Posa.

3.6.12 Lake Rotomanuka (north and south)

Depth	8.7 m (North), 4.8 m (South)
TA	Waipa District Council
WRC zone	Central Waikato
Land tenure	Wildlife management reserve administered by Department of Conservation
Lake area	12.3 ha (North), 5.4 ha (South)
Estimated catchment area	479 ha
Catchment land use	Dairy/lifestyle
Percent native vegetation cover in catchment	11.35%
Applicable joint agency accord/MOA	Waipa Peat Lakes Accord
Lake level in WRP	✓ 50.1m (Moturiki datum)
Identified as significant wetland (WRP Rule 3.7.7)	✓
Identified as Priority 1 stock exclusion	✓

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (17)	Lake type (36)	WRC zone (7)
8	3	3	2
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Rotomanuka is a complex of two lakes, located about 12km south of Hamilton City, near Ohaupo. Lake Rotomanuka lies on the edge of the Moanatuatua peat bog, which has been largely drained for agricultural development. The lake is administered by the Department of Conservation as a wildlife management reserve. It is the oldest (at 27,000 years) and deepest lake in the Hamilton basin (McCraw 2013).

The lake was formerly a single water body, but through drainage has become two separate lakes that are hydrologically linked by a 10 ha wetland. These two lakes are known as Rotomanuka North and South (or Gin Lake), but is considered to be a single management unit (or lake complex) for the purposes of Waikato Regional Council's management.

The Rotopiko/Serpentine Lakes are hydrologically linked to the Rotomanuka Lakes, so form part of the wider catchment, which is predominantly used for intensive dairy farming.

Water quality information has been collected from the lakes throughout the years and is summarised in the table below. Waikato Regional Council collected monthly water quality samples from both lakes between 1995 and 2001, and has continued to sample Rotomanuka North up to the present time.

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
1977[a]	4.0	0.6					
1981[b]	1.6-3.5	14	703	17		6.2-8.0	1.2
North							
1988[c]	2.55	12	820	20		6.8	
1997[d]			611				0.8
1995-2001[e]	1.78	18.1	792	28	4.94	7.27	3.57
2003-2007[f]	2.0	12	910	20	5.0		
2006-2010[g]					4.7		
2007/2008[h]	1.14	13.7	995	15	4.8	7.4	6.45
2008/2009[i]	1.54	13	1141	14	4.74	7.06	4.5
2009/2010[i]	1.51	14	1178	10	4.65	7.4	4.9
2010/2011[i]	1.57	10	1182	18	4.75	7.2	5.03
2012/2013[i]	0.94	7.3	955	16.3	4.67		
South							
1988[c]	0.6	86	3180	115		7.3	
1997[d]			6151	500			37
1995-2001[e]	0.66	171	2482	147	6.64		

a Chapman and Boubee (1977)

b Davenport (1981); WVA based on 10 samples taken between January and March 1981

c Page (1988) Mean of two samples taken between December 1987 to March 1988. – surface sample figures have been used for TP and TN

d Thompson and Greenwood (1997) based on 2 samples collected over a 10 day period during the 1997 summer. Results have been transposed from graphs so are indicative of values

e Average of samples taken between October 1995 and 2001- Barnes (2002b) – WRC data

f WRC data reported in Hamilton et al (2009)

g WRC shallow lakes water quality monitoring programme – monthly samples. Data taken from Nutrient enrichment of shallow lakes State of the Environment Indicator: WRC (2012)

h WRC shallow lake health indicators programme (December/March) (Neilson & Hamer 2008).

i WRC shallow lake health indicators programme (average of December, March, May samples)

The results show a distinct difference in water quality between South and North Lakes, which is likely to be a result of influenced by their physical (i.e. depth) differences. North Lake is presently eutrophic but has far better water quality than South Lake which was extremely nutrient enriched (i.e. hypertrophic) when it was last surveyed in 2001 (Barnes 2002a and 2002b).

Analysis of rotifer communities during the summer of 2007/08 suggested that the lake was supertrophic (Duggan, 2008).

A possible deterioration in water quality in north lake was detected between 1995 – 2001 with a reduction in secchi depth and increase in TP and TN (Barnes 2002a). This is likely to have been associated with the collapse of submerged plants in 1996/97 (Barnes 2002b). Results collected by the Council for 2003-2007 can be compared with earlier studies which indicate that concentrations of phosphorus, nitrogen and chlorophyll a

were similar to the corresponding values in the early 1980's (Hamilton et al. 2010). Analysis of recent data indicates that between 2006 and 2010 there has effectively been no change in trophic state in Lake Rotomanuka (WRC 2012).

There have been numerous surveys of submerged plants at the lake since 1977. Champion et al (1993) described the values of the submerged vegetation at Lake Rotomanuka. Thompson and Champion (1993) subsequently encouraged stakeholders to make a significant effort to protect the lake because of these and other values. Unfortunately however, submerged plants collapsed in the lakes sometime in the late 1990s. In the most recent (2007) submerged plant survey, some plants were located but they were not present at sufficient density to generate a Lake SPI score (Edwards et al, 2007).

Research carried out in 2001-2002 concluded that in-situ recovery of submerged vegetation was unlikely to be substantial due to inadequate seed reserves in the lake sediments (de Winton, 2002). Further research demonstrated that the light climate in the littoral zones of the lake was adequate for the establishment of translocated plants, but that the presence of exotic fish (particularly rudd) precluded this when plants were not protected by fish exclosures (de Winton and Taumoepeau, 2005). The presence of exotic fish, in particular rudd, is therefore a particular concern and appears to be a major impediment in the reestablishment of submerged vegetation in the lake.

Lake Rotomanuka is fully fenced to exclude stock. Over time, Waipa District Council has acquired several esplanade reserves to extend the width of the retired lake margin. Using Natural Heritage Funding, Waipa DC has also recently acquired c.7ha of land that adjoins South Lake. Despite these additions, the lake margin is still narrow in some places and would benefit from further extension to exclude stock from low lying areas that are wet in winter and vulnerable to pugging. This is particularly evident in the area between the two lakes on the southern side.

Stockdale (1995) studied the hydrological requirements of the Rotopiko and Rotomanuka lakes and made various recommendations for the sustainable management of these lakes. She recommended that water levels be maintained within 20cm of the ground surface for at least 95% of the time to sustain peat forming communities.

Lake Rotomanuka was identified in Section 3.7.4.5 of the WRP as requiring a minimum level to be set. A wooden v-notch weir was constructed in the lake outlet in April 2006, and its height was introduced to the WRP as the minimum level for the lake (50.1 m Moturiki datum). During 2010 the height of the weir was resurveyed to assess whether there had been any movement. This survey determined the height of the "v" to be 50.08 m indicating that the weir was stable.

Ongoing intensive dairy farming, as the predominant catchment land use, is a threat to the water quality in the lake. Up until 2007 there was continuing discharge of treated dairy effluent into a tributary of the lake (contrary to Barnes, 2002a), however all discharge in the catchment is now to land.

Various projects are currently underway to improve land use practices within the Rotomanuka lakes catchment to improve the condition of the lakes. The Department of Conservation has worked with the major landowner in the catchment to prepare a farm plan that identifies options for them to reduce the impacts of their farming operation on the lakes whilst maintaining their current levels of production. New Zealand Landcare Trust is also undertaking a project at the lakes (funded by the Waikato River Clean Up Trust) that involves community consultation and engagement, preparation of nutrient management plans for landowners within the lakes' catchment, assessment of options

to mitigate nutrient and sediment inputs to the lakes, and preparation of a Community Catchment Action Plan. This project is due for completion in 2015.

Most recently, Lake Rotomanuka has been selected as a candidate site for a 10 year restoration programme in a conservation – dairy industry partnership initiative between DOC and Fonterra. The project plan for this work is currently being developed and should begin in practice in 2014/15. A bathymetric survey has recently been undertaken as part of this project. This survey compared the results bathymetric data collected in 1979

A man-made drain (modified water course) extends from the Serpentine lakes catchment and enters the Rotomanuka lakes via the southern lake. Thompson and Greenwood (1997) consider this to be an important water source for the lakes (to maintain water levels) that compensates to some extent for extensive drainage of peat to the north and east of the lakes.

Lake Rotomanuka is identified as a significant wetland in section 3.7.7 of the WRP. The invert level of the lake outlet drain was surveyed in 2007 to provide data to support rule 3.7.4.6 that protects the lake from the effects of further drainage with 200m of the reserve boundary.

Options for management and acquisition of information:

- continue regular monitoring of water quality and lake health indicators
- provide funding support where possible to revegetation programmes on Crown and private land
- work with other agencies (eg Waipa District Council, DOC, Fonterra and NZ Landcare Trust) to implement the recommendations and outcomes of current programmes
- where possible provide funding support for planting and weed control within the lake margin
- assist Waipa District Council where possible to facilitate public access to the lake.

3.6.13 Lake Rotongata

Depth	Unknown
TA	Waipa District Council
WRC zone	Upper Waikato
Land tenure	Private under QEII Covenant
Lake area	5.3 ha
Estimated catchment area	144 ha
Catchment land use	Dairy
Percent native vegetation cover in catchment	0%
Applicable joint agency accord/MOA	Waipa Peat Lakes Accord
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 Stock Exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (17)	Lake type (36)	WRC zone (4)
46	15	28	4
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Rotongata is a small privately owned peat lake, with three (3) owners that is located to the south of Maungatautari. The lake is covered by three QEII covenants associated with each respective property owner.

Lake Rotongata is bounded on all sides by deep peat, but has been substantially drained and is now much smaller and shallower than it was originally.

Waikato Regional Council holds no recent water quality information about Lake Rotongata although some historic information has been collected and is summarised in the table below. It is clear from these results that the lake has experienced poor water quality and high nutrient concentrations (TN & TP).

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
1977[a]	0.26	117.5					
1988[b]	0.3	192	2810	720		6.0	
1997[c]			3283	750			20

a Chapman and Boubee (1977)

b Page (1988) Mean of two samples taken between December 1987 to March 1988 – surface sample figures have been used for TP and TN

c Thompson and Greenwood (1997) based on 2 samples collected over a 10 day period during the 1997 summer. Results have been transposed from graphs so are indicative of values

No lake SPI surveys have been conducted at Lake Rotongata, and it is unknown whether the lake supports any submerged aquatic vegetation at present.

The lake had a very narrow riparian margin that was willow dominated when visited by Thompson & Greenwood (1997). At that time, dense gorse and blackberry were also reported from the south-eastern side of the lake as an indicator of over-drainage (Thompson & Greenwood 1997). When Waikato Regional Council visited the site in 2009, at least one landowner had removed some willows from along their section of the lake margin and had under planted with some native plants (including flaxes) (T. Balvert pers. comm.).

Lake Rotongata is used for recreational hunting and is known to support large numbers of mallard and paradise ducks. The New Zealand dabchick, a species of conservation significance, has also been reported from the lake. Prior to drainage, Lake Rotongata also supported large numbers of koura and some native leeches (*Richardsonianus mauianus).* Eels are thought to have arrived in the lake once the outlet was formed at the lake in the early 1950s (Thompson & Greenwood 1997).

Lake Rotongata is currently mostly fenced. Thompson & Greenwood (1997) observed fencing on the eastern, western and northern sides of the lake of varying standard, but observed gaps at the southern end of the lake that provided stock access to the lake.

Lake Rotongata is identified in section 3.7.4.5 of the WRP as a significant peat lake that requires a minimum lake level to be established[13]. Insufficient water levels, inadequate riparian margins, the presence of weed species, and poor water quality are identified as the main threats to the lake (Thompson & Greenwood 1997). They recommended that a number of actions be undertaken, including: fencing and planting an increased riparian margin; undertaking weed control; establishing an ecologically derived lake level; and constructing nutrient and silt traps on all inflowing drains.

Waikato Regional Council staff visited Lake Rotongata in 2009 with QEII staff after becoming aware of drainage and willow clearance activities that had been undertaken near the lake margin by the landowner. At that time, QEII and the associated landowners indicated a desire and willingness to improve the future management of the lake. As yet, this does not appear to have occurred.

Options for management and acquisition of information:

- establish a lake level setting project for Lake Rotongata to implement s.3.7.4.5 of the WRP
- survey lake health indicators
- advocate for the inclusion of Lake Rotongata in the upcoming WRP reviews as a priority for stock exclusion
- work with landowners in the lake catchment and QEII to encourage best management practices on farm (including fencing & riparian management) – possibly through the establishment of a Lake Care Group, and/or development of a management plan.

3.6.14 Rotopiko/Serpentine Lakes

Depth	4 m (North), 3.6 m (South), 4.4 m (East)
TA	Waipa District Council
WRC zone	Waipa
Land tenure	Wildlife management reserve administered by Department of Conservation Recreation & esplanade reserves administered by Waipa District Council
Lake area	5.3 ha (north), 8.3 ha (south), 1.6 ha (east)
Estimated catchment area	163 ha
Catchment land use	Dairy and lifestyle blocks
Percent native vegetation cover in catchment	8.12%
Applicable joint agency accord/MOA	Waipa Peat Lakes Accord
Lake level in WRP	✓ 54.92m (Moturiki Datum) - Variation for inclusion in the WRP (section 3.7.4.5)
Identified as significant wetland (WRP Rule 3.7.7)	✓
Identified as Priority 1 stock exclusion	✓

Lake biodiversity ranking (Wildland Consultants 2011a)

[13] in the third priority group of lakes to be introduced (by variation) into the WRP

Regional (71)	District (17)	Lake type (36)	WRC zone (15)
6	2	2	1
Figures in brackets indicate the total number of lakes included in assessment.			

The Serpentine/Rotopiko Lakes complex consists of 3 small peat lakes (known as North, East and South lakes) that are located near Ohaupo. An ephemeral wetland area (known as Winter Lake) exists between, and connects the North and South Lakes in winter. The lakes were once part of a much larger waterbody (Lake Rotopiko) that existed prior to drainage and development of the Moanatuatua peat bog during early European occupation (Champion et al. 1993, Neilson et al. 2004). This drainage resulted in the complete loss of Round Lake, which previously existed nearby. All of the lakes are embedded in deep (>4m) bog peat[14] but North lake is embedded in peat of a greater depth that exceeds 5m and extends up to 8m (Thompson & Greenwood 1997).

The lakes are managed by the Department of Conservation as part of a c.30 ha Wildlife Management Reserve. Waipa District Council administers an adjoining 7.7ha Recreation Reserve that extends partway between South and East lakes, as well as additional esplanade reserves that have recently been acquired around South and North lakes. Waipa District Council has indicated its intention to improve amenity values and public access to the lakes in future.

Lake Rotopiko would have been a closed system naturally, but is now connected to the surrounding 135ha catchment via several inlets and an outlet on the eastern side of the lake complex. The lakes receive inflow from surrounding farm drains, rainfall, and runoff from the adjacent State Highway. The outlet drain presently runs to Lake Rotomanuka, although it has been suggested that this outflow should be re-directed in future to bypass Lake Rotomanuka. Concerns have been expressed about the hydrological effects on the Rotomanuka lakes of removing this important water source (Keith Thompson, *pers. comm.*).

Water quality monitoring has been undertaken in the lakes sporadically over the last 30 years, with early surveys undertaken by students and staff from the University of Waikato in 1977 and 1988. On the recommendation of Barnes (2002a), the lakes were included in Waikato Regional Council's shallow lake health monitoring programme and water quality sampling has been undertaken by Waikato Regional Council at .monthly intervals since 2002 for North and East lakes, and twice[15] annually since 2007 for South Lake. These results indicate that the Rotopiko lakes are eutrophic – supertrophic, although they are in better overall condition than other shallow lakes in the Waikato region overall (B.Vant *pers comm*.).

	Mean SD (m)	Mean Chl *a* ($mg\ m^{-3}$)	Mean TN ($mg\ m^{-3}$)	Mean TP ($mg\ m^{-3}$)	Estimated TLI	pH	Turbidity (NTU)
1997[c]			1071	30			8.0
North Lake							
1977[a]	1.30	1					
1988[b]	1.50	44	1035	25		7.0	
2002/2003 – 2005/2006[d]	2.12	21	1078	33			

[14] Except for a small section of the perimeter of South Lake
[15] in December and March

2003-2007 [e]	2.2	18	1120	31			
2006-2010[f]					4.9		
2006/2007[g]	2.12	11	1120	23	4.7	7.5	2.2
2007/2008[h]	1.90	26	1306	35	4.9	7.35	3.55
2008/2009[i]	2.02	10	1331	23	4.76	7.2	2.63
2009/2010 [i]	1.84	13	1425	26	4.94	7.13	2.64
2010/2011 [i]	1.96	20	1646	28	5.11	7.37	3.7
2011/2012 [i]	1.76	16	1063	29	4.95	7.03	2.83
2012/2013 [i]	1.65	14	931	30	4.89		
South Lake							
1977[a]	1.00	11					
1988 [b]	1.10	29	1215	40		7.0	
2003-2007 [e]	1.3	11	1000	34			
2006-2010[f]					5.2		
2007/2008[h]	1.32	10.7	996	34	4.9	7.2	4.8
2008/2009[i]	1.02	27	1034	52	5.4	7.16	7.4
2009/2010[i]	0.97	16	1610	39	5.33	7.1	6
2010/2011[i]	1.28	15	1155	38	5.12	7.1	4.83
2011/2012[i]	1.23	13	865	37	4.99	7.03	6.13
2012/2013 [i]	0.80	12.3	642	28	4.89		
East Lake							
1977[a]	1.80	8					
1988 [b]	1.35	42	1220	35		6.75	
2002/2003-2005/2006 [d]	1.82	17.8	1114	29			
2003-2007[e]	1.3	16	1160	18			
2006-2010[f]					4.9		
2007/2008[h]	1.35	16	1155	18	4.89	7.2	3.6
2008/2009[i]	1.38	14	1413	27	5.05	5.8	2.3
2009/2010[i]	1.42	15	1569	40	5.21	6.8	3.0
2010/2011[i]	1.28	10	1672	20	4.93	6.7	2.72
2011/2012[i]	1.38	6	1328	22	4.74	6.6	2.3
2012/2013 [i]	1.30	13.5	933	22	4.84		

a Chapman & Boubee (1977)

b Page (1988) Mean of two samples taken between December 1987 to March 1988 – surface sample figures have been used for TP and TN

c Thompson and Greenwood (1997) based on 2 samples collected over a 10 day period during the 1997 summer. Results have been transposed from graphs so are indicative of values. It is not clear from which lake samples were taken.

d WRC data

e WRC data reported in Hamilton et al (2009)

f WRC shallow lakes water quality monitoring programme – monthly samples. Data taken from

Nutrient enrichment of shallow lakes State of the Environment Indicator: WRC (2012)

g WRC shallow lake health indicators programme (pilot study) (December, January and March) (Neilson *et al.* 2007).

h WRC shallow lake health indicators programme (December/March) - Nielson & Hamer (2008)

i WRC shallow lake health indicators programme (average of December, March, May samples)

The lakes are subject to nutrient enrichment from adjoining land uses, and North and East lakes have experienced increasing TN during the last 3-5 years. Fortunately, this has not led to substantial algal growth as the lakes are thought to be phosphorus limited (B.Vant pers comm.). Chlorophyll a has actually decreased in North Lake over the past 3-5 years. Significant increases in TP and chlorophyll a were observed in South Lake during December 2008 which may have occurred as a result of vegetation collapse, although these levels normalised by March 2009 (B.Vant pers comm.).

The hydrological and nutrient processing dynamics of the Rotopiko Lakes were studied in detail by Stockdale (1995) and Hamill (1995), respectively.

The Rotopiko Lakes have and continue to support significant and almost wholly native submerged native plant communities – a rare feature in lakes regionally and nationally. In 2001 marginal and submerged plant communities were surveyed in North Lake (Barnes 2001a). This work confirmed the importance of these communities, but also confirmed the presence of rudd in the lakes for the first time, which was identified as a particular threat to the plant communities. Recommendations from this work formed the basis of a focussed research and management programme by a range of agencies.

Submerged plant surveys have been undertaken annually for the Department of Conservation at the Rotopiko lakes since 2001 either using the full Lake SPI assessment or a quick survey method. Previous survey information also exists for vegetation surveys that were undertaken in the early 1990's.

North Lake has maintained consistently high Lake SPI scores and remains one of the only Waikato lakes with a well-developed, solely native submerged plant community that is dominated by pondweeds and charophytes. North lake is the highest scoring water body in the Waikato region, although its submerged vegetation is showing signs of stress (ie high epiphytic burden, signs of fish grazing and fluctuating depth limits) and may be at risk of major decline (Edwards et al. 2010, Burton et al. 2014). The invasive bladderwort, *U.gibba* was recorded from North Lake for the first time in 2010 but remains sparse. It also occurs in the other Rotopiko Lakes (de Winton 2011; Burton et al. 2014).

East Lake also supported a wholly native vegetation and had a very high Lake SPI score until February 2010 when an invasive bladderwort (*Utricularia gibba*) was first detected in the lake. The Lake SPI score for East Lake has declined as a result of the reduced abundance of native pondweeds and rapid establishment and expansion of *U. gibba* (de Winton 2010; de Winton 2011; Burton et al. 2014). Charophyte meadows remain well developed, although a retraction in plant depth limits may indicate deteriorating light conditions or increased pest fish grazing which will affect the recovery of aquatic plants (Edwards et al. 2010, de Winton 2010). Lake SPI scores for East lake have declined from 89-91% up until 2009 to scores of 49-66% since 2011 (Burton et al. 2011).

Submerged native plants also occur at South Lake but fluctuate considerably as the lake oscillates between a vegetated and de-vegetated state (Edwards et al. 2010). These fluctuations are in part due to the shallow bathymetry of this lake, such that small environmental changes can result in a considerable change in habitat for submerged plants (Burton et al. 2014). In 1992, South lake supported sparse populations of native submerged vegetation of low species diversity, that were insufficient to generate a Lake

SPI score (Champion et al. 1993, Edwards et al. 2010). In 2005 and 2007 South Lake supported substantial native pondweeds and scored highly although this recovery was not sustained, and vegetation levels in 2009/10 fell below the Lake SPI survey threshold again. Since early 2010, further surveys (September 2010, April 2011, and April 2012) indicate some recovery of submerged plants with Lake SPI scores of 84%, 74% and 67%, respectively. These scores are lower than previous scores generated from 2006-08, which are most likely to reflect the presence of *U gibba* - which was first detected in South lake in March 2009[16] (de Winton 2011; de Winton 2010). South lake currently has a restricted band of pondweeds around the shoreline, with some charophyte patches in shallow water (Burton et al. 2014). South Lake is thought to be on the cusp between a vegetated and non-vegetated state, due to the large fluctuations in pondweed cover.

In addition to important and vulnerable native macrophyte communities, the Rotopiko/Serpentine lakes also support marginal and emergent vegetation that is mostly comprised of native species. DOC and Waipa District Council have undertaken substantial planting and weed control programmes to improve the quality of vegetation in these areas. The peat forming rush, *Sporodanthus traversii* has also recently been successfully translocated to the Rotopiko Lakes (from Torehape peat bog) in a project undertaken by NZ Landcare Trust.

The lakes support a good diversity of native fish, and contain rare and valuable populations of shortfinned eels that have not been commercially fished (Wildland Consultants 2009). Unfortunately, the lakes also support several exotic fish species, including *Gambusia*, rudd, brown bullhead catfish and goldfish. Koi carp are not thought to occur in the lakes.

A number of native bird species utilise the lakes, including the Australasian bittern, New Zealand dabchick, North Island fernbird, spotless crake, black shag, little black shag and little shag, which are of conservation significance (Wildland Consultants 2009).

After the discovery of rudd in the Rotopiko lakes in 2001, and due to concerns about their impact on the submerged plant communities, a collaborative research project between DOC, Waikato Regional Council and NIWA was undertaken during 2002 and 2003 to test physical control methods to control and/or eradicate rudd within the lake system. After two years of intensive netting, it became evident that fine-mesh monofilament gill nets could be potentially viable and cost-effective means of achieving control of coarse fish populations in the lake (Neilson et al. 2004). DOC has continued to maintain a netting programme at the lakes in order to maintain fishing pressure on coarse fish populations. In addition, DOC have also explored a range of other options (including the use of rotenone) to eradicate or control coarse fish populations within the lake complex. A literature review and toxicological testing of rotenone have been undertaken to assess the potential future use of rotenone at the lakes. DOC has also recently installed a fish barrier in the outlet drain between the Serpentine/Rotopiko lakes and Lake Rotomanuka with a view to preventing invasive fish movement into the lakes.

The Rotopiko/Serpentine lakes are identified in Section 3.7.4.5 of the WRP as requiring a minimum level to be set. A level setting exercise has been completed and in March 2009, in consultation with other agencies, Waikato Regional Council constructed a single timber weir in the outlet drain at a height 54.92m (Moturiki datum). The weir has increased lake levels locally, but its effect is localised to a slight increase in the lake level of Serpentine North, and increased water levels between the weir and the area upstream of it. The effect of the weir declines with distance to the other lakes, and it is likely that

[16] The first record (from March 2009) of the invasive bladderwort *U. gibba* from lakes within the Waikato Region.

additional control structures would be required (i.e. at the outlet of East Lake) to achieve better control on their minimum water levels.

The Rotopiko lakes are identified as a significant wetland in the WRP. Surveys of the invert level of the lake outlet drain were undertaken in July 2007[17] to obtain baseline data for the implementation of rule 3.7.4.6. which controls drainage within 200mm of the reserve boundary.

Lake Rotopiko is fully fenced to exclude stock. A riparian margin of at least c.20m extends around all of the lake which is administered by DOC. This margin has been augmented by Waipa DC in recent years. An additional strip of land was acquired by Waipa DC several years ago that further extends the riparian margin around the eastern side of East lake, and more recently the Council acquired an additional 1.8 ha esplanade reserve that extends around most of North Lake and part of the way down the western side of winter lake. These extensions begin to implement the advice of Thompson & Champion (1993), who assessed the esplanade requirements of several Waipa lakes and recommended that a margin of at least 50m be secured around most of the lakes as a general guideline.

A management action plan was developed for the Serpentine Lakes by NIWA for the Department of Conservation in 2007 (de Winton et al; 2007). The plan primarily focused on actions for which the Department had a major responsibility or role, and has been at least partially implemented

The main threats to the Rotopiko lakes include: peat shrinkage arising from drainage activities on adjoining land; nutrient enrichment (arising from increased intensity of agriculture in the catchment); the presence of pest fish and their effects on submerged native plants; and the recent arrival of the invasive bladderwort *Utricularia gibba* to the lakes complex.

Because of their high natural values, the Rotopiko lakes are a very high priority for protection and management amongst agencies and stakeholders (including DoC, EW, Fish & Game, Iwi and Waipa District Council), that are working together to protect and improve the ecological condition of lakes. A co-ordinated multi-agency programme of work has achieved:

- improved riparian management - including acquisition of additional land, control of grey willows in the lake margins[18], and planting programmes;
- control of invasive fish (rudd) to reduce the impacts of these species on submerged native vegetation. This work has involved a research trial to establish a viable netting method (Neilson et al. 2004), and consideration of eradication options involving the use of rotenone (Dean-Speirs 2008, Ling 2013)
- construction of a fish barrier downstream of the lakes
- assessment of nutrient input sources to identify remediation options (reported by Sukias et al. 2006)
- a pilot study involving diversion of an existing surface flow drain to an infiltration filter that was installed on the margin of North lake to reduce nutrient inputs[19] (Sukias et al. 2009)
- a PhD project investigating nutrient attenuation options (i.e. silt traps and constructed wetlands) at Waikato peat lakes (including the Rotopiko lakes)
- establishment of a surveillance programme to detect new invasive species;

[17] by Bloxam, Burnett & Olliver & peer-reveiwed by Harrison-Grierson
[18] which also serves to increase wind exposure and increase mixing, therefore preventing stratification
[19] primarily P

- attempted eradication[20] of parrot's feather (*Myriophyllum aquaticum*) identified in the drain that runs under SH3 adjacent to south lake;
- recreation of a restiad peatbog adjacent to East lake through the translocation of restiad rushes (*Sporodanthus* and *Empodisma* species) from Torehape;
- bathymetric surveys of the lakes;
- preparation of farm plans for properties adjoining the lakes.

Over the last 2 years, Waikato Regional Council, DOC and Waipa District Council have undertaken a catchment study that involves: (i) monitoring nutrient and sediment inputs to Lake Mangakaware from 3 main drain inflows; and (ii) preparation of whole farm system plans for dairy farms adjoining the lake to identify options for adjoining landowners to improve their environmental and economic performance. Reducing sediment and nutrient losses to the lake is a key focus of these plans.

Waipa District Council has also signalled a desire to improve the amenity values of the lakes and increase public access to them. With support from the Council, the National Wetland Trust (NWT) is proposing to develop a Wetland Visitors Centre on recreation reserve land administered by Waipa District Council that is adjacent to the lakes. Using funding from the Waikato River Clean Up Trust, WCEET and others the NWT has recently constructed a pest proof fence around East lake with a view to introducing threatened animals and birds to the area. Intensive pest control is being undertaken within this area in preparation of this.

Options for management and acquisition of information:

- continue to work closely with other agencies and stakeholders to protect and enhance the condition of the Serpentine/Rotopiko lakes (through the Waipa Peat Lakes Accord), and to implement the actions that have been identified for the lakes;
- in conjunction with other agencies, review the effectiveness of the weir to determine whether additional structures are required to control minimum levels at East and North lakes
- continue regular monitoring of water quality and lake health indicators
- support DOC to continue pest fish removal work to protect native submerged aquatic plants;
- implement PhD recommendations to install and/or upgrade constructed wetlands on lake inflows to reduce nutrient inflows;
- further assess options for modelling and managing the effects of land use on the lakes to maintain and/or improve the condition of the lakes;
- support DOC to assess invasive fish eradication and management options at the lakes complex.

[20] the effectiveness of which can only be determined after 5 years surveillance monitoring

3.6.15 Lake Rotopotaka

Depth	Unknown
TA	Waipa District Council
WRC zone	Waipa
Land tenure	Wildlife management reserve administered by Department of Conservation
Lake area	2.8 ha
Estimated catchment area	76 ha
Catchment land use	Dairy/drystock
Percent native vegetation cover in catchment	1.01%
Applicable joint agency accord/MOA	Waipa Peat Lakes Accord
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (17)	Lake type (36)	WRC zone (15)
36=	14	22	12
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Rotopotaka is a small modified peat lake situated on the edge of the Moanatuatua peat bog that is administered as a Wildlife Management Reserve by the Department of Conservation.

The lake is in a degraded condition overall, receiving inflows from surrounding farmland via several drains and possibly also via a sub-surface tile drain (Thompson & Greenwood 1997). The lake's water quality was studied by the staff and students of the University of Waikato in 1977 and 1988, and was described as being shallow and eutrophic. In 1997, Thompson & Greenwood reported that the lake had high nutrient concentrations overall, with the highest sodium and chloride concentrations of any of the lakes that they sampled - which were attributed to large inputs from a distant catchment. Waikato Regional Council holds no more recent water quality information for Lake Rotopotaka. A summary of historical data is presented in the table below.

	Mean SD (m)	Mean Chl *a* ($mg\ m^{-3}$)	Mean TN ($mg\ m^{-3}$)	Mean TP ($mg\ m^{-3}$)	Estimated TLI	pH	Turbidity (NTU)
1977[a]	0.5	1.86					
1988[b]	0.15	661	8610	1000		9.07	
1997[c]			4203	500			32
a Chapman & Boubee (1977) b Page (1988) Mean of two samples taken between December 1987 to March 1988 – surface							

sample figures have been used for TP and TN

c Thompson and Greenwood (1997) based on 2 samples collected over a 10 day period during the 1997 summer. Results have been transposed from graphs so are indicative of values

Lake Rotopotaka has low botanical values due to its shallow depth and limited amounts of open water (Thompson & Greenwood 1997). The lake supported submerged plants in the 1970's when it was visited by staff and students of the University of Waikato - including *Nitella hookeri*, *Egeria densa* and *Elodea canadensis* (Chapman & Boubee 1977). These submerged species had all but disappeared by 1991 when the lake was surveyed by Champion et al. (1993) who found extremely sparse amounts of *Nitella hookeri* only. Page (1988) concluded that plant growth in the lake was nitrogen limited.

Raupo (*Typha orientalis)* was the dominant emergent plant species in the lake until recently, and is reported to have covered more than half of the lake area in 1991 (Champion et al. 1993). Since that time, the formerly extensive beds of raupo have been removed and are reported to occupy a much smaller area. When visited in 2007 the lake was reported to be very shallow, drought prone, and almost entirely covered by *Azolla* sp. (K. Neilson, pers. comm.). The lake was subsequently revisited in 2010 when it appeared that further vegetation (predominantly raupo) clearance and lake lowering had taken place.

Lake Rotopotaka is a waterfowl breeding area, and is used for recreational hunting. The lake is thought to be used by a low diversity and abundance of native waterfowl (Wildland Consultants 2009), although spotless crake and Australasian bittern have been recorded from the site in the past which are of conservation significance. Eels are also known from the lake, which is also thought to contain exotic fish species including catfish, goldfish and *Gambusia* (Wildland Consultants 2009).

Lake Rotopotaka is surrounded by farmland, and has a very narrow riparian margin that is dominated by exotic trees, particularly grey willow that extends beyond the water's edge. Rubbish has also been dumped in numerous areas within the margin of the reserve area.

The lake is not permanently fenced. When the lake was last visited by Council staff, a temporary electric fence had been erected along a portion of the reserve boundary but this was partly submerged. DOC and Waipa District Council have been working with at least one adjoining landowner to determine reserve boundaries with a view to installing boundary fencing and improving the management of riparian margins.

Lake Rotopotaka is identified in section 3.7.4.5 of the WRP as a significant peat lake that requires a minimum lake level to be established[21]. The lake level appears to have been lowered in 2009/10 during drainage activities. As a result of ongoing risks, the lake remains a high priority for installation of a water level control structure.

Insufficient water levels, inadequate riparian margins, the presence of weed species, and poor water quality are identified as the main threats to the lake (Thompson & Greenwood 1997). They also identified peat shrinkage as a key issue for the lake – particularly shrinkage of the peat basin located to the west of the lake (that flows into the lake), and shrinkage to surrounding land subject to rapid oxidation through cropping.

Thompson & Greenwood (1997) recommended that a number of actions be undertaken, including: fencing and planting an increased riparian margin; undertaking weed control; establishing an ecologically derived lake level; and diversion of inflowing drains so that they do not discharge directly into the lake.

[21] in the third priority group of lakes to be introduced (by variation) into the WRP

Options for management and acquisition of information:

- survey lake health indicators
- establish a lake level setting project for Lake Rotopotaka to implement rule. 3.7.4.5 of the WRP
- advocate for and support where possible fencing of the wildlife management reserve and road reserve boundaries by the Department of Conservation, Waipa District Council and private landowners.
- advocate for and support where possible planting and weed control within the fenced wildlife management reserve and road reserve boundaries by the Department of Conservation, Waipa District Council and private landowners.
- work with landowners in the lake catchment to encourage best management practices on farm (including fencing & riparian management).

3.6.16 Lake Ruatuna

Depth	3.2 m
TA	Waipa District Council
WRC zone	Waipa
Land tenure	Wildlife management reserve administered by Department of Conservation
Lake area	13 ha
Estimated catchment area	190 ha
Catchment land use	Dairy
Percent native vegetation cover in catchment	0%
Applicable joint agency accord/MOA	Waipa Peat Lakes Accord
Lake level in WRP	✓ 38.61m (Moturiki Datum) – to be varied in the WRP to new level of 38.75m (section 3.7.4.5)
Identified as significant wetland (WRP Rule 3.7.7)	✓
Identified as Priority 1 stock exclusion	✓

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (17)	Lake type (36)	WRC zone (15)
15	6	7	4
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Ruatuna is a small peat lake that is located south-west of Ohaupo, within a Wildlife Management Reserve administered by the Department of Conservation. Waipa District Council administers important esplanade reserves on the western side of the lake that adjoins the DOC reserve, as well as a recreation reserve with public access, campsites and a building containing basic kitchen and bathroom facilities. This area has previously been used for education activities but visitation has declined due to water quality deterioration. Waipa District Council is currently upgrading the facilities at Lake Ruatuna to encourage public usage.

Whilst Lake Ruatuna would previously have been hydrologically isolated, it is now connected to the Mangaotama Stream (and then the Waipa River) via an outlet drain and receives direct inflows from multiple drains.

Little recent information is available about the lake's water quality, although water quality sampling was undertaken by the University of Waikato in 1977, and by the WVA from January – March 1982 when the lake was mesotrophic (Chapman & Boubee 1977; Town 1982b). Secchi depth measurements are consistently low (less than 1m) which reflects low levels of light transparency typical of dystrophic lakes. Whilst average TP concentrations were relatively low in 1982, some individual samples exceeded eutrophic levels. Since that time the lake has become nutrient enriched and is eutrophic – hypertrophic at present (Champion et al. 1993, Page 1988, Wildland Consultants 2009). Waikato Regional Council does not hold any recent water quality data. Available data is summarised in the table below.

	Mean SD (m)	**Mean Chl *a* (mg m^{-3})**	**Mean TN (mg m^{-3})**	**Mean TP (mg m^{-3})**	**Estimated TLI**	**pH**	**Turbidity (NTU)**
1977 [a]	0.49	28.7					
1982[b]	0.7-1.0	18.9		54		7.09	
1988[c]	0.55	142.3	1860	155		7.9	
1997[d]			2868	330			19

a Chapman & Boubee (1977)

b Town (1982b) weekly water quality sampling undertaken by WVA between January - March 1982 – surface sample figures have been used for TP and TN

c Page (1988) Mean of two samples taken between December 1987 to March 1988

d Thompson and Greenwood (1997) based on 2 samples collected over a 10 day period during the 1997 summer. Results have been transposed from graphs so are indicative of values

No submerged vegetation occurred within Lake Ruatuna when it was last surveyed, and the lake was reported to be devoid of vegetation (Champion et al. 1993, Edwards et al. 2010). In 1997 the lake was reported to "only just" retain submerged plants (Thompson & Greenwood 1997). Poor water clarity is thought to be the main suppressant of plant growth, although rudd are now found in the lake and will affect aquatic plant regeneration.

Lake Ruatuna is mostly fully fenced, although some sections of fence may benefit from replacement. The lake has a substantial riparian margin that has been extended (to 60-70m) recently with the acquisition of additional esplanade reserves by Waipa District Council. Weed control (particularly willow) and planting work within the riparian margin is beginning, and is undertaken by DOC, Waipa District Council and other volunteer groups.

Lake Ruatuna has also recently been selected as a candidate site for a 10 year restoration programme in a conservation – dairy industry partnership initiative between DOC and Fonterra. The project plan for this work is currently being developed and should begin in 2014/15. A bathymetric survey has recently been undertaken to create an updated bathymetric map of Lake Ruatuna.

Peat shrinkage arising from drainage activities within the catchment is a major threat to the sustainability of peat lakes, including Lake Ruatuna (Thompson & Champion 1993). The Lake Ruatuna Wildlife Management Reserve is listed in Section 3.7.7 of the WRP and is therefore subject to rule 3.7.4.6 regarding drainage within 200 m of the property

boundary. The outlet drain has been surveyed in order to provide baseline information in the event of future drainage activities.

Section 3.2.4.7 of the WRP establishes a minimum level for Lake Ruatuna of 38.61m (Moturiki Datum). Weirs have historically existed at the lake outlet, but the two previous structures were illegally removed in 1997 and 2002. In 2011, Waikato Regional Council constructed a new weir at a height of 38.75m (Moturiki Datum) to maintain and/or improve water quality, marginal vegetation and the peat substrate. This height represented a lake level that had been exceeded 80% of the time since water level records began in June 2005 (excluding drought data from 2008). It has recently become apparent however, that the water level record for the lake was incorrect due to a c.90mm error in benchmark surveys. As a result, the weir has been installed at a level that is c. 90mm lower than it should have been, and that the level will be exceeded for more than 80% of the time.

It appears that very few fish and invertebrate surveys have been undertaken in Lake Ruatuna, although the presence of the herbivorous fish rudd (*Scardinius erythrophthalmus*) has been confirmed by Edwards *et al.* (2010), and eels are also known to occur in the lake. Adjoining landowners who fish the outlet of the lake confirm that the majority of species caught are bullhead catfish (Paula Reeves, Waipa District Council, *pers. comm.*). In 2007, NIWA staff observed large numbers of empty mussel shells on the lake bed in several places, which confirmed that the lake has previously supported mussel populations (Burton et al. 2014).

The lake is utilised by a range of waterfowl and protected bird species including NZ dabchick, scaup and spotless crake (Wildland Consultants 2009). A number of maimai are located around the lake, and a lake users group was formed in 2013 to progress restoration projects at the lake.

Options for management and acquisition of information:

- advocate for and support where possible ongoing weed control and planting around lake margin by the Department of Conservation, Waipa District Council and volunteer groups
- support water quality and catchment management initiatives at Lake Ruatuna to reduce sediment, nutrient and other contaminant inputs to the lake (eg DOC-Fonterra project)
- survey lake health indicators.

3.7 Waitomo district

3.7.1 Lake Rotokotuku (Kotukutuku)

Depth	c.8m
TA	Waitomo District Council
WRC zone	Waipa
Land tenure	Private land
Lake area	1.1 ha
Estimated catchment area	18.5 ha
Catchment land use	Drystock
Percent native vegetation cover in catchment	11.35%
Applicable joint agency accord/MOA	✕
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (7)	Lake type (36)	WRC Zone (15)
Data deficient	Data deficient	Data deficient	Data deficient
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Rotokotuku is a small peat lake located approximately five kilometres southeast of Te Kuiti in the Waitomo district. The lake and surrounding wetland are associated with peat soils within a karst catchment that is situated c.250m above sea level. The surrounding wetlands cover approximately 6.8ha and comprise modified manuka shrubland and Machaerina (ex Baumea) sedgeland with a significant pest plant component.

The wetlands are fed via groundwater, rain, and surface runoff during high rainfall events but there are no streams or drains entering the system. The outlet stream flows for approximately 530m to the northwest before entering a tomo. Water quality monitoring data gathered by the Waikato Regional Council (unpublished 2011) shows that the lake is acidic (pH 5.2), and has elevated nutrient levels. These and other data collected suggest that Lake Rotokotuku is of comparable quality to Lake Maratoto in the Waipa district which is considered to be the best quality peat lake in the region (Dean 2011a).

Lake Rotokotuku was sampled by Waikato Regional Council in 2010/2011as part of the Council's shallow lake health indicators project. Data is presented in the table below.

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
2010/2011[a]	0.59	31	986	57	5.59	5.23	2.42
a WRC shallow lake health indicators programme (average of December, March, May samples)							

In May 2014, NIWA visited Lake Rotokotuku to carry out a Lake SPI survey. They reported that vegetation was largely absent from the lake on account of its strongly peat stained waters, and the lack of available habitat on the steep sided littoral margins of the lake. Only one submerged plant species was recorded - the non-native *Callitriche stagnalis* which was found at the lake access where terrestrial vegetation has been cleared. While the lake was recorded to be devegetated, this does not reflect the condition of the lake in this instance, since it is unlikely to have ever supported submerged plants because of its dystrophic nature (Burton et al. 2014).

In the late 1970s, the Waikato Valley Authority undertook a preliminary assessment of wetlands in the Waitomo County and described this lake as being surrounded by a (c.6 ha) high quality manuka dominated wetland with some more open areas, including raupo (Henriques 1979). Some grazing pressure on the adjoining wetland was observed at that time, but despite this, Henriques (1979) recommended that the lake be considered for scientific reserve status because of its high scientific and wildlife values at that time.

The lake was also assessed by Moynihan (1986), who ranked it as being of moderate value on the basis of its wildlife values. His report indicates that the lake was used at that time by common waterfowl species, and was a breeding site for paradise shelduck. He described it as having 50% open water at that time, with emergent flaxes and rushes present. Kahikatea, manuka and bracken fern were also observed around the lake.

A restoration plan has recently been prepared (Dean 2011b) for Waikato Regional Council. The plan summarises that the aim of the restoration should be to restore the

lake and surrounding wetlands to a functioning ecosystem in a near natural state. Specific goals include:

1. Reduce pest plant cover to less than 5% within five years.
2. Establish 90% indigenous plant cover across the whole site within eight years.
3. Implement mustelid control within three years.
4. Maintain lake quality parameters (TN, TP, Secchi depth, chlorophyll α, rotifer TLI) and wetland nutrients at current levels or lower.

In October 2011, WRC staff visited Lake Rotokotuku to undertake fish surveys. Spot invertebrate samples were also taken from the lake margins at this time. The invertebrate samples contained a variety of insects including caddis flies, damsel flies, dragon flies, true flies, water fleas (copepods), and ostracods. Importantly, the samples contained the first record of Triplectidina (a caddis fly) from the Waikato region since 1994. The snail, Glyptophysa was also present in the samples is of conservation significance (S. Moore, Landcare Research *pers comm.*).

Eleven fyke nets were set in the lake and around 40 Gee minnow traps were set in the wetland margins which looked promising for black mudfish. The nets/ traps were left overnight and retrieved the next day. A total of 14 shortfin eels were caught in the fyke nets, whilst no fish were caught in the traps set in the wetland margin of the lake. Large numbers of insects were also caught in the traps and nets - principally damsel flies and dragon fly larvae (Odonates), and water boatman (Corixidae beetles) that were exceptionally abundant.

The low abundance of eels in the lake reflects the difficulty that they would experience recruiting to the lake, since eels spawn at sea and juveniles must travel back to freshwater environments to grow. The eels were in very good physical condition, which is probably due to the good supply of invertebrates, and a lack of competition for food.

The lake is not identified a Priority 1 stock exclusion water body in the WRP however since the development and implementation of the restoration plan, and with funding support from WRC, the lake has been fully fenced.

Some pest plant control has also recently been undertaken along with some restoration planting in line with the restoration plan (Adrian Jepson, WRC, *pers comm.*)

Options for management and acquisition of information:

- collect relevant information to enable Lake Rotokotuku to be scored using the ‘Methodology for ranking lake ecosystems for lake ecosystems for biodiversity management in the Waikato region’ to enable its inclusion in the SNA Lake Ecosystems assessment
- re-survey lake health indicators
- work with the adjoining landowner to implement the Lake Rotokotuku wetland restoration plan
- work with the adjoining landowner to encourage best farm management practices (including fencing & riparian management)

4 Waikato riverine lakes

Riverine lakes have been formed through fluvial (river) processes as rivers carry and deposit sediments along the river banks. River processes can enlarge existing water bodies, create natural levies that separate and form new waterbodies, or leave a remnant oxbow waterbody when it changes course.

Lake ecosystems associated with large river basin floodplains are highly productive, diverse and interconnected. Their ecology (e.g. nutrient dynamics and biological diversity) is highly dependent upon riverine hydrology and flood frequency, so must be considered within the wider context of river processes.

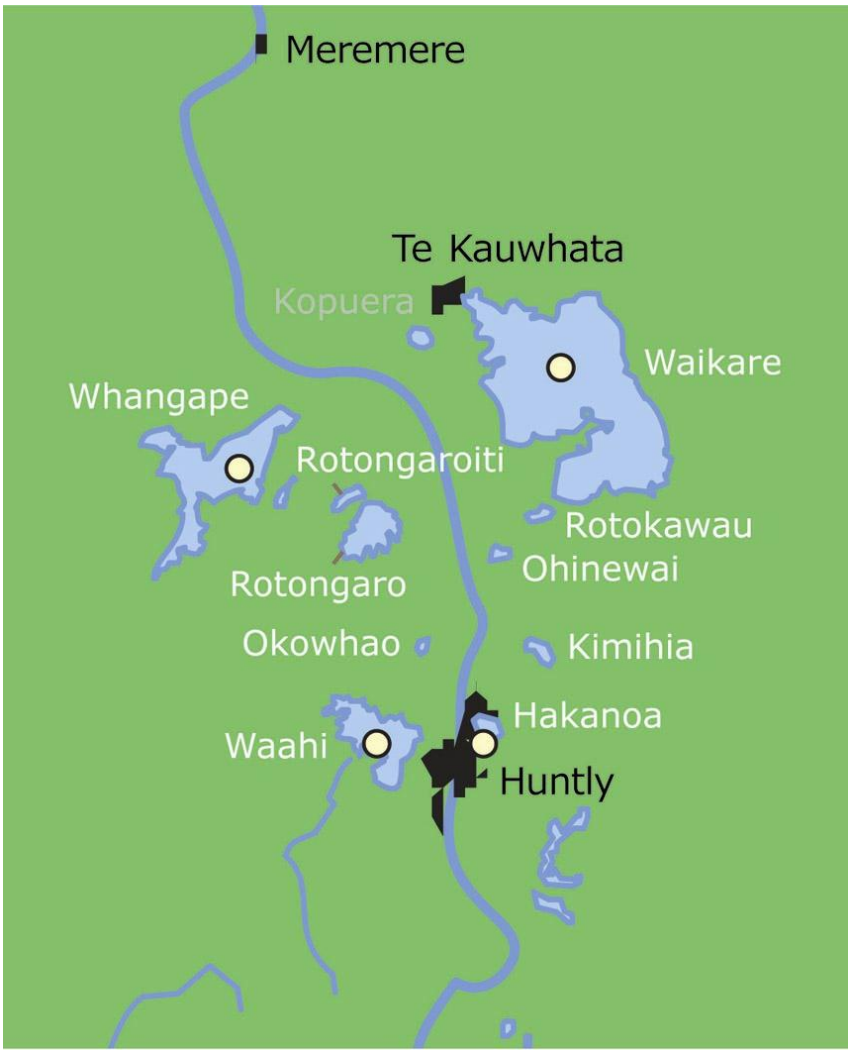


Figure 6 Location of riverine lakes associated with the Waikato River (source – Environment Waikato)**.**

There are 14 riverine lakes in the Waikato region that are associated with the Waikato (12 lakes), Waipa (Te Otamanui Lagoon) and Piako Rivers (Patetonga Lagoon). The lakes within the catchment of the lower Waikato River are part of an extensive river floodplain wetland system that includes Lakes Whangape, Waahi, Waikare and the internationally important Whangamarino wetland. Together, these environments create a nationally significant, interconnected system of open water, wetlands and swamp environments that provide important habitat for native plants and animals.

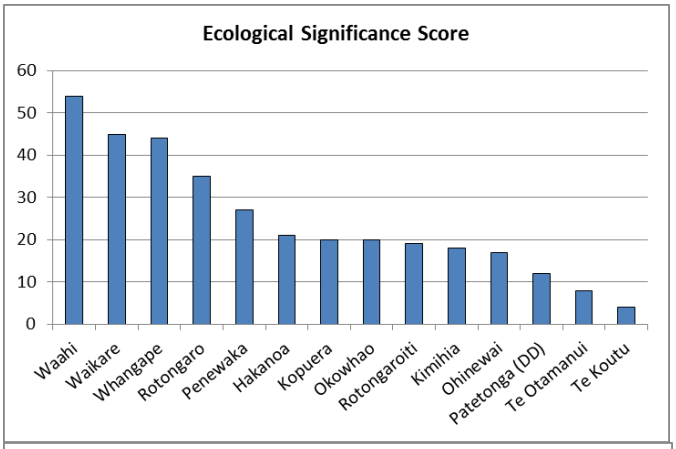
The riverine lakes share common properties with the peat lakes in terms of depth, catchment influences and vulnerability to change. All of the Waikato riverine lakes are naturally shallow (<5m depth) and their higher wind fetch has resulted in increased internal sediment re-suspension and reduced water clarity, especially following collapse of submerged vegetation. This group of lakes contains some of the largest shallow lakes in the region including Waikare (3442 ha), Whangape (1450 ha) and Waahi (522 ha).

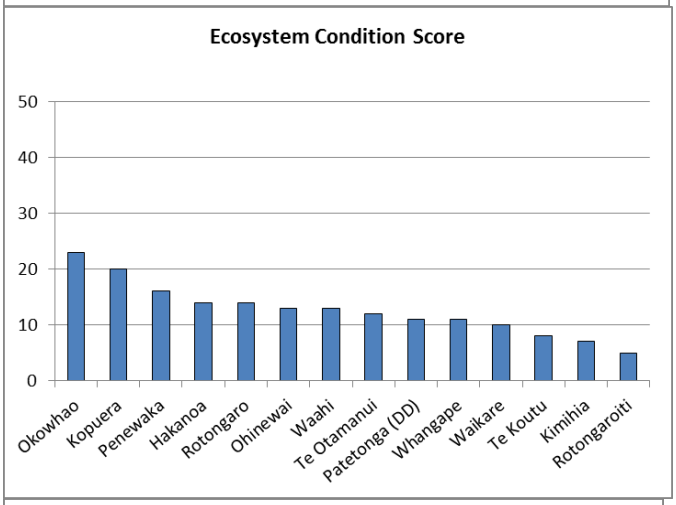
More is known about riverine lakes than any other lake type partly due to comprehensive biological surveys carried out in the 1980's and 1990's. Figure 7 shows scores for different aspects of assessment process that was undertaken to score and rank lake ecosystems for their biodiversity values (Wildland 2011).

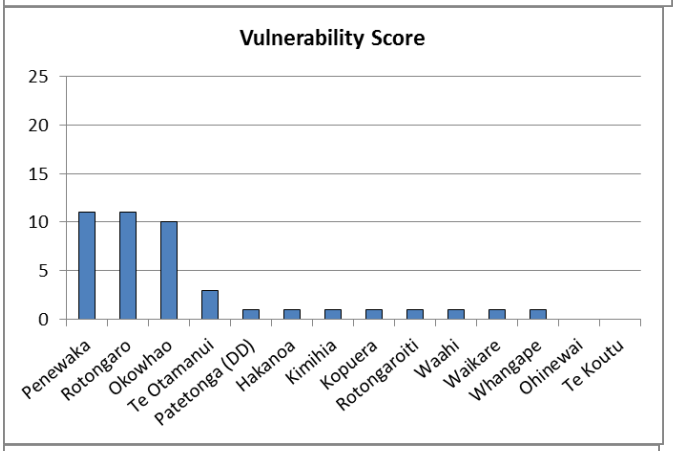
The large riverine lakes have some of the highest ecological significance scores for shallow lakes. This is because their size generally confers a high diversity of habitats and they tend to have large marginal wetlands that sustain a diversity of species, many of which are threatened.

Ecosystem condition scores are low to moderate for all riverine lakes. All riverine lakes have poor water quality and most experience regular algal blooms. The interconnectedness of the riverine lakes facilitates the spread of pest fish and weeds so that almost all riverine lakes support pest fish and wetland weeds. Their poor condition translates to low vulnerability scores since many of the threats to these lakes have already occurred and are well entrenched.

Potential outcome scores are mostly low, as they recognise the practical difficulties and uncertainties associated with shallow lake resotoration – particularly for the large riverine lakes that have highly modified hydrological regimes and extremely large catchment sizes.







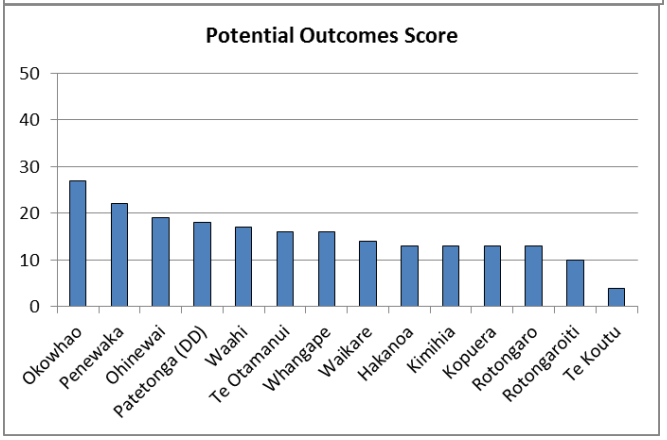


Figure 7 Riverine lake scores for different aspects of the lake prioritisation method used to score and rank the biodiversity values of lakes in the Waikato region (Wildland Consultants 2011a).

4.1 Hauraki district

4.1.1 Lake Patetonga

Depth	Unknown
TA	Hauraki District Council
WRC zone	Waihou/Piako
Land tenure	Wildlife management reserve administered by Department of Conservation
Lake area	4.9 ha
Estimated catchment area	120997 ha
Catchment land use	Unknown
Percent native vegetation cover in catchment	7.32%
Applicable joint agency accord/MOA	✕
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (2)	Lake type (15)	WRC zone (4)
Data deficient	Data deficient	Data deficient	Data deficient
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Patetonga is an artificially created lake situated to the west of the Piako River. The river and associated stopbanks separate the lake and associated 16 ha reserve from the Kopuatai peat dome.

The lake is administered by DOC and has been created and managed for waterfowl habitat and duck hunting. Lake Patetonga and other ponds nearby are of particular interest to the Upper Piako Wetland Management Association. The lake fills up during spring tides and water is retained by a sluice gate structure that is administered by the Department of Conservation (I. Sara *pers. com.)*. The Mangawhero floodgate is situated further downstream between the sluice gates and the Piako River.

Waikato Regional Council holds no information about the water quality of the lake but anecdotal information from DOC suggests that the lake water is of a similar quality to the Piako River (i.e. poor), and that the lake has a thick muddy bottom sludge.

The lake was fully fenced by DOC in 2004, and is subject to a spraying and planting programme. It is understood that *Glyceria maxima* is a major problem in the area and is likely to be an ongoing issue as floating mats of *Glyceria* move up and down the Piako River (A. McDonald, DOC *pers. comm.*).

Although Lake Patetonga is identified as being data deficient, it is unlikely to be a high priority for Waikato Regional Council to gather information because it has been

constructed for hunting purposes and is administered by the Department of Conservation.

4.2 Waikato district

4.2.1 Lake Hakanoa

Depth	2.5 m
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Wildlife refuge reserve administered by the Department of Conservation
Lake area	52 ha
Estimated catchment area	613 ha
Catchment land use	Drystock/urban
Percent native vegetation cover in catchment	20%
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✓ 8.51m (Moturiki datum)
Identified as significant wetland (WRP Rule 3.7.7)	✗
Identified as Priority 1 stock exclusion	✗

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (15)	WRC zone (29)
42=	18=	8=	17=
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Hakanoa is situated immediately east of the Waikato River within a 73 ha Wildlife Refuge that is administered by the Department of Conservation. The lake is associated with several wetlands (including lagoons), and is situated within a partly urbanised sub-catchment. The western shore of the lake has been developed into an open domain area (Huntly domain). The lake has been heavily modified and is in a degraded condition.

The lake receives a variety of inputs which include at least two streams that drain pastoral farmland and enter the lake from the south and east, and stormwater inputs from the residential areas located to the west, south and north of the lake. Stormwater also enters the lake from commercial premises on the western side of the lake, which includes a fertiliser store (Hudson *et al.* 2008; John Gumbley, DOC *pers. comm.*). Under high flow conditions, the lake also receives water from the Waikato River which may transport plant and/or animal species (Hudson *et. al.* 2008).

Waikato Regional Council has monitored the water quality of Lake Hakanoa since 2003. A comparison of 2003-2007 results against earlier studies indicates that concentrations of phosphorus, nitrogen and chlorophyll a were similar to those measured in the early

1980's (Hamilton *et al.* 2010). As a consequence of its poor water quality, the lake now experiences regular algal blooms and occasional fish kills. Analysis of recent data indicates that there has been a statistically significant improvement in the trophic state of Lake Hakanoa between 2006 and 2010 (WRC 2012).

	Mean SD (m)	**Mean Chl *a* (mg m^{-3})**	**Mean TN (mg m^{-3})**	**Mean TP (mg m^{-3})**	**Estimated TLI**	**pH**	**Turbidity (NTU)**
1980[a]	0.3-1.7					7.0-8.5	
2003-2007[b]	0.4	90	2300	160			
2006-2010[c]					6.0		
2010/2011[d]	0.45	45	1835	93	6.12	8.53	29
2012/2013[d]	0.51	39.3	1908	86	6.04		

a Town (1980); WVA based on 10 samples taken between 7 January and 12 March 1980

[b] WRC data reported in Hamilton et al (2009)

[c] WRC Shallow lakes water quality monitoring programme – bi-monthly samples. Data taken from nutrient enrichment of shallow lakes, State of the Environment Indicator: WRC (2012)

[d] WRC shallow lake health indicators programme (average of December, March, May samples)

Surface reaching beds of the invasive *Egeria* densa were observed before 1970 and dominated Lake Hakanoa in the early 1970s. In the mid to late 1970's the lake surface was sprayed with herbicide, which resulted in a permanent decline in aquatic plants and associated water quality changes (Champion et al. 1993). The lake is currently de-vegetated and has been in this condition for more than 20 years.
It is unlikely that submerged aquatic species will regenerate in the lake due to its poor water clarity, the presence of pest fish, and fragile sediments that are prone to re-suspension. As a consequence, any plant regeneration will be light-limited and would be restricted to shallow areas only.

The lake is inaccessible to stock and has been so for at least 2 years. Approximately 95% of the lake margin is currently fenced, although fencing is of variable standard (mostly 5-7 wire). The status of fencing in the wetland/swamp area is unknown, and it is estimated that up to 200m of fencing may be required to upgrade this section. It is understood that many of the lakeside plantings involve exotic species that have been planted for their amenity values.

A minimum level of 8.51m (Moturiki datum) has been established for Lake Hakanoa which is included in the Waikato Regional Plan (section 3.2.4.7). The weir at the lake outlet is administered by Waikato District Council, and it is reported[22] to require maintenance. Lake water levels are also reported to reach flood levels that close parts of the Domain and walkway. At these times, pumps are operated to reduce lake levels (Waikato District Council 2012).

Lake Hakanoa supports large numbers of waterfowl, and is also known[23] to provide habitat for the threatened Australasian bittern, spotless crake, black shag and little black shag. It is likely that many birds move between the lake, the Waikato River, and other lakes nearby (e.g. Waahi, Puketirini, Kimihia).

The lake is likely to support reasonable populations of shortfinned eels and possibly smelt, although a screened flapgate is located on the outflow to the Waikato River which

[22] Reported in the Lake Hakanoa Reserve Management Plan
[23] or is likely to have recently supported

limits fish passage except under high flows and may prevent large eels from migrating downstream (Wildland Consultants 2009). Invasive fish (including koi carp, brown bullhead catfish, and rudd) occur in the lake and probably exacerbate water quality problems through their feeding behaviour (via sediment disturbance and re-suspension, and aquatic plant grazing).

Restoration of Lake Hakanoa is a high priority for Waikato District Council and the Lake Hakanoa Care Group. Waikato District Council recently contracted NIWA to review options for improving the condition of Lake Hakanoa. This report concluded that the management of inputs and the dynamics of particulate material within the lake will ultimately determine the extent of (in-lake) rehabilitation possible, although additional information relating to the basic limnology, hydrology, and nutrient budget of the lake catchment is required in order for firm management recommendations to be made (Hudson *et. al.* 2008). Since then, Waikato District Council has contracted the University of Waikato to model restoration scenarios for the lake. Waikato Regional Council has supported elements of this project through the Environmental Initiatives Fund.

The wetlands and emergent vegetation zones associated with Lake Hakanoa support a variety of native and exotic vegetation types. Grey willow dominates the wetland areas, but native plants occur in reasonable abundance in the understorey. Native plants dominate the emergent vegetation but several exotic species (gypsywort and water primrose) are also common. Weed control and planting in these areas would improve biodiversity (Wildland Consultants 2009).

A Reserve Management Plan for Lake Hakanoa and Huntly Domain has recently been approved by Waikato District Council (on 28 August 2012), which establishes the following management objectives for Lake Hakanoa:

- to progressively improve Lake Hakanoa's water quality and health (Objective 4)
- to actively manage and enhance lakeside and lake margin vegetation and wetland areas (Objective 5)
- to manage and enhance passive recreation opportunities around the lake (Objective 6)
- to provide for integrated management of the reserve (Objective 7).

Whilst the plan has been prepared by Waikato District Council, the reserve is formally administered by DOC. It is understood that the agencies are working towards establishing a formal agreement that transfers control and management responsibilities from DOC to Waikato District Council.

Various actions have been identified to achieve the objectives of the management plan, including the following that have been assigned to Waikato Regional Council (in conjunction with others):

- mapping surface water inflows,
- remedial works to treat, divert or remove lake inflows;
- working with Waikato DC to remedy point source inflows;
- supporting restoration of wetlands and waterways on adjoining private land;
- review of the coarse fishery management to reduce impacts on water quality;
- identify options to mitigate lake shore erosion;
- participation in the Lake Hakanoa Governance Committee.

Wildland Consultants (2012b) identified further actions to improve biodiversity and wetland values around Lake Hakanoa including weed control and planting in wetlands to the South and East of the lake, and in emergent vegetation zones.

The key options for WRC's future management and acquisition of information include:

- support Waikato District Council to implement the Lake Hakanoa Management Plan
- continuing to monitor lake water quality and shallow lake health indicators.

4.2.2 Lake Kimihia

Depth	<1.0 m
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Wildlife management reserve administered by Department of Conservation
Lake area	58 ha
Estimated catchment area	1485 ha
Catchment land use	Drystock/indigenous vegetation
Percent native vegetation cover in catchment	41.06%
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✓ 8.0m (Moturiki datum)
Identified as significant wetland (WRP Rule 3.7.7)	✗
Identified as Priority 1 stock exclusion	✗

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (15)	WRC zone (29)
47=	20=	10=	20
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Kimihia is located approximately 5km north east of Huntly township and is situated within a predominantly pastoral catchment (Champion et al 1993).

Lake Kimihia has been greatly modified as a result of open cast coal mining, which was initiated in the early 1940s. To access coal reserves beneath the lake, a stop bank was constructed across the lake to enable the southern portion to be drained. As a result, the lake was reduced in size from 316 ha to 58 ha. Mining waste (overburden) was deposited into the remaining lake as well as the drained portion, as operations expanded northward (Buxton & Russell 1988). The drained portion was subsequently used as a settling basin and later developed into a 32 ha constructed wetland (Kimihia wetland) for the treatment of discharge water from the Kimihia Pit and Huntly East coal mine. The remaining area of Lake Kimihia is now extremely shallow and degraded, with a flood gate positioned at its outlet (Buxton & Russell 1988).

In 1975, the lake water was reported by the NZ Electricity Department to be turbid and yellow-brown in colour, with a secchi depth of 0.6m. This poor water clarity is attributed to the continued re-suspension of bottom sediments (from wind/wave action) that occurs as result of the shallow nature and large size of the lake (Champion et al. 1993).

Lake Kimihia was most recently sampled during December 2006 – March 2007 by Waikato Regional Council as part of a project investigating indicators of shallow lake health. These results indicate that the lake is presently hypertrophic with very poor water quality (Neilson *et al.* 2007). Zooplankton sampling was also undertaken at this time and rotifer inferred TLI scores are similar - i.e. hypertrophic (Duggan 2007). The lake is reported to experience algal blooms in summer as a result of high nutrient loads.

	Mean SD (m)	**Mean Chl *a* (mg m^{-3})**	**Mean TN (mg m^{-3})**	**Mean TP (mg m^{-3})**	**Estimated TLI**	**pH**	**Turbidity (NTU)**
1975[a]	0.6						
1980[b]	0.1-0.1					6.1-8.2	
2006/2007[c]	0.13	198	3320	329	7.4	8.1	198.7
2009 [d]	0.13		1700	150			

a NZED (from Champion et al. 1993)
b Town (1980); WVA based on 10 samples taken between 7 January and 12 March 1980
c Waikato Regional Council Shallow Lake Health indicators programme (pilot study) (December, January and March) (Neilson *et al.* 2007)
d Waikato University sampling results 21 May 2009 – B. Hicks pers. comm.

No submerged aquatic plants have existed in Lake Kimihia since an extensive vegetation collapse occurred between 1975-1980. In 1975, *Egeria densa* was rooted throughout the entire lake basin and had formed surface reaching beds over 50% of the lake surface. Although *Egeria* was dominant, other submerged species[24] also occurred within the lake (Champion et al. 1993). By 1980, *Egeria* was sparsely distributed, although still surface reaching in places. This situation had changed by 1991, when a sparse, amphibious turf comprised of *Glossostigma elatinoides,* and a small patch of waterlilies (*Nymphaea alba*) were the only species recorded from the lake (Champion et al. 1993). At this time, a moderate diversity of native plants were reported from the wetland and emergent zones of the lake, however cattle access has apparently degraded this vegetation in the intervening period (Wildland Consultants 2009).

In 1993, Champion et al. (1993) suggested that the lake may not be capable of supporting submerged vegetation in its current state as a result of sediment resuspension, poor water clarity, and/or the presence of an extensive marginal sudd. Champion et al (1993) reported that this sudd covered 48% of the lake margin[25] and extended over water up to 0.8m depth, thereby restricting the amount of shallow water habitat available with sufficient light to support submerged plants.

Lake Kimihia is not identified as a priority stock exclusion waterbody in the WRP, and stock currently have access to the lake. Waikato Regional Council has contributed to the cost of some fencing around the lake, but approximately 3000 m of the lake margin requires fencing to exclude stock.

A minimum level of 8.0m (Moturiki datum) was set for Lake Kimihia in the late 1980s under the Water & Soil Conservation Act 1967 (Buxton & Russell 1988). This minimum level is now included as a provision of the Waikato Regional Plan[26]. A timber and rock weir was installed at the outlet of Lake Kimihia by the Department of Conservation in the early 1990's.

[24] including *Nitella* hookeri and *Potamogeton ochreatus*
[25] especially on the western fringe
[26] 3.2.4.7 Standards for maximum and minimum flows and levels

The lake is presently dominated by exotic fish species, including goldfish, catfish, mosquito fish and koi carp, and rudd (Golder Associates 2009), but populations of native galaxiids are known to occur in some of the lake tributaries. Eight fish species[27], commonly found in similar habitats in the lower Waikato River catchment, were caught from the lake in 1991 during fisheries surveys (Chisnall *et al.* 1991). Interestingly, no common smelt (migratory or lacustrine forms) were located during this survey, and banded kokopu, giant kokopu and lamprey that have previously been recorded from the lake, were similarly absent. Chisnall *et.al.* (1991) suggest that the absence of lucustrine smelt is most likely to be the result of poor water clarity and the loss of submerged macrophytes in Lake Kimihia. The absence of species that were expected but not found (including smelt, lamprey, large galaxiids and black mudfish) was not fully explained, but may be related to access restrictions at the outlet weir, avoidance of poor water quality or sampling limitations.

The lake is a difficult management prospect in its current state as it is affected by multiple stressors operating at a large scale (i.e. modified hydrology, high levels of nutrient and sediment inputs). Despite this, the lake and associated tributaries still support a diverse suite of native plants and animals, including kokopu species. It is clear that substantial biodiversity gains could be achieved with weed control, fencing and riparian planting. Wetland complexes associated with Lake Kimihia (e.g. the eutrophic Kimihia wetland) also receive low nutrient mine discharge water. Management could substantially improve these wetlands (John Gumbley, DOC *pers. comm.*).

In 2011, Solid Energy New Zealand Limited, New Zealand Transport Agency and Waahi Whaanui Charitable Trust initiated a multi-agency restoration project for the Lake Kimihia Catchment. The overall aim of this project was "to restore and enhance the Kimihia catchment" through catchment management, riparian planting, pest fish management and drainage modifications (as appropriate) to improve the water quality entering the Waikato River at its confluence with Kimihia Stream. This project has received funding from the Waikato River Clean Up Trust since 2011[28]. Work to date has involved fencing, retirement and planting of two wetland areas (of 4.1 ha and 3.3. ha, respectively) at Fisher Road that adjoin the Kimihia Stream, and work on a wetland at Ralph Rd. Further work was proposed for 2013-2015 that involved: (i) the design and installation of fish gates to enable koi to migrate from (but not re-enter) Lake Kimihia; (ii) manual fishing to reduce the density of koi carp in Lake Kimihia: and (iii) riparian planting on the Kimihia Stream.

The Huntly section of the Waikato Expressway is currently being designed and investigated in more detail but is likely to be constructed in 2015-2019 following recent approval to construct the Huntly section of the Waikato Expressway. As part of the this project, a road corridor has been designated that runs close to Lake Kimihia with mitigation works involving lake margin fencing, plant pest control, and re-vegetation (including for nearby wetland areas that will be managed by Fish & Game).

Options for WRC's future management and acquisition of information:

- advocate and support (where possible) for land owners, including DOC, to complete fencing to exclude stock from the entire lake margin
- survey lake health indicators
- advocate for the inclusion of Lake Kimihia in upcoming WRP reviews as a priority for stock exclusion;
- work with members of the Waikato Lakes & Wetlands MOA Group to support (where possible) restoration initiatives at Lake Kimihia.

[27] i shortfinned eels, inanga, common bully, mosquitofish, grey mullet, brown bullhead catfish, goldfish, and rudd
[28] $57,385 in 2011, $95,000 in 2012, and $138,000 in 2013

4.2.3 Lake Kopuera (Rangiriri)

Depth	1.5 m
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Waikato-Tainui (formerly Wildlife management reserve administered by Department of Conservation)
Lake area	52 ha
Estimated catchment area	250 ha
Catchment land use	Dairy/drystock
Percent native vegetation cover in catchment	24.5%
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✕ drains into Lake Waikare
Identified as significant wetland (WRP Rule 3.7.7)	✓
Identified as Priority 1 stock exclusion	✓

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (15)	WRC zone (29)
36=	15	7	14
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Kopuera is situated south of Te Kauwhata township in close proximity to Lake Waikare. The lake bed was formerly administered by the Department of Conservation as a Wildlife Management Reserve, but has been transferred to Waikato-Tainui as part of the Waikato River Settlement Act (2010). The lake has high cultural significance.

Lake Kopuera drains into Lake Waikare, and was lowered in 1965 as part of works associated with the creation of the Lower Waikato River Flood Control Scheme (Champion et al. 1993). There are no direct inflows into Lake Kopuera, and the lake outflow has been modified so that it now drains into Lake Waikare (Town 1982b).

Waikato Regional Council holds no recent water quality information for Lake Kopuera. Town (1982) reports water quality results from 10 sampling visits to Lake Kopuera undertaken between 5 January -10 March 1982. At that time, the lake was described to be a very turbid green colour. The lake's poor water condition was attributed to direct inputs of cowshed effluent and/or the effects of lake level changes.

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity
1982[a]	0.05-0.2	292.8		383.4		9.4	
a Town (1982b) weekly water quality sampling undertaken by WVA between January - March 1982							

No submerged macrophytes were observed in Lake Kopuera in 1982, during water quality sampling (Town 1982b). Submerged plant surveys in 1991 confirmed that plants were still absent from the lake, which was attributed to extremely poor water clarity (Champion et al. 1993).

The margin of Lake Kopuera is partially fenced, and it is estimated that approximately 2500 m fencing would be required to completely fence the entire lake margin. To date, WRC has contributed to the costs of 2.1km of fencing around the margin of Lake Kopuera.

Because Lake Kopuera is identified as a significant wetland in s. 3.7.7 of the WRP, a resource consent is required to create new drains or deepen existing drains within 200m of the legal property boundary.

Lake Kopuera still supported a relatively intact narrow marginal fringe when it was surveyed in 1990, despite having been invaded by grey and crack willow (Champion et al. 1993). Champion et al (1993) suggested that lake level fluctuations associated with the flood control scheme may have allowed willows to colonise almost to the lake edge at the expense of emergent vegetation. An unusual and undescribed form of *Baumea* was observed at the lake, which is thought to be either a hybrid or new species (Champion et al. 1993).

Most recently, the wetland associated with the lake was assessed for pest control by Wildland Consultants & Epro Ltd (1999) who described it as comprising manuka scrub with *Coprosma tenuicaulis* that graded into willow forest on the margins. They observed damage to the understorey from stock grazing, and recommended fencing to prevent further weed invasion (particularly by willow and royal fern).

Town (1982) observed that the lake and adjoining areas offered good habitat for a range of waterfowl including grey duck, fernbird, bittern, and spotless crake, which are of conservation significance. Catfish, eels, *Gambusia*, common bullies, goldfish, koi carp and rudd are known to occur in the lake (Wildland Consultants 2009).

Because there is very little recent information about the condition of Lake Kopuera, it is a priority to visit the lake and assess its present condition and management requirements.

Options for management and acquisition of information:

- seek approval to visit Lake Kopuera and survey lake health indicators
- work with Waikato-Tainui and other MOA members and interested parties to assess the lake and its future management requirements
- advocate and support Waikato-Tainui where possible, to improve the management of the lake margins (including fencing, willow control and planting)
- work with landowners in the lake catchment to encourage best management practices on farms to reduce nutrient and sediment inputs.

4.2.4 Lake Ohinewai

Depth	4.5 m
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Stewardship land administered by Department of Conservation
Lake area	16 ha
Estimated catchment area	347 ha
Catchment land use	Drystock/dairy
Percent native vegetation cover in catchment	2.67%
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✓
Identified as Priority 1 Stock Exclusion	✓

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (15)	WRC zone (29)
42=	18=	8=	17=
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Ohinewai is a shallow, moderately peat stained lake that is located within a pastoral catchment on the outskirts of the Ohinewai Peat Bog. The lake is fed by a single major drain entering the lake from the south west. The lake drains from its north eastern end into Lake Rotokawau, which is subsequently connected to Lake Waikare and eventually the Waikato River.

The catchment of Lake Ohinewai has been developed for agriculture and affected by considerable drainage, which has substantially lowered lake levels (Boswell et*. al.* 1985; Champion et. al*.* 1993; Wildland Consultants 2009).

Water quality sampling was undertaken by the WVA between January-March 1981 and 1983-1984 (Davenport 1981; Boswell *et al.* 1985; McLea 1986). In 1981, the lake was moderately peat stained with low turbidity, although the presence of brown algal species resulted in elevated chlorophyll *a* concentrations at that time. At that time the lake was classified as being eutrophic (Davenport; 1981).

Water quality sampling was most recently undertaken by Waikato Regional Council between 2006 and 2013 as part of a project investigating indicators of shallow lake health. The water quality data from these surveys are presented in the table below, which indicate that water quality has declined significantly and the lake is presently hypertrophic.

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
1981[a]	0.6 -1.3	62	1182	80	-	6.3-8.9	3.1
1983/84[b]	-	52-57	1400-1500 (TKN)	70-84	-		
2006/2007[c]	0.44	44	1785	126	6.2	7.4	28.6
2007/2008[d]	0.425	66	1801	135	6.35	7.7	26.5
2008/2009[e]	0.475	31	2108	106	6.27	7.96	26.33
2009[f]	0.45		2100	88			
2009/2010[e]	0.382	56	2494	131	6.43	7.46	29.66
2010/2011[e]	0.48	67	1959	109	6.28	7.66	27.43
2011/2012[e]	0.56	39	2920	143	6.26	7.0	18.5
2012/2013[e]	0.39	56	1650	151	6.34		

a Davenport (1981); WVA based on 10 samples taken between January and March 1981

b Median values reported in McLea (1986)

c WRC shallow lake health indicators programme (pilot study) (December, January and March) (Neilson *et al.* 2007).

d WRC shallow lake health indicators programme (December/March) Neilson & Hamer (2008)

e WRC shallow lake health indicators programme (December/March/May)

f Waikato University sampling results 28 May 2009 – B.Hicks pers. comm.

In 1981, the lake was dominated by *Egeria densa*, which covered 40% of the lake's surface and up to 80% of the lake bottom, and grew to a maximum depth of approximately 3m (Champion et al. 1993; Davenport 1981). *Potamogeton ochreatrus* and *Myriophyllum elatinoides* were also reported to have occurred in low abundance with *Egeria* (Davenport 1981). An unseasonal die back of *Egeria* was observed in December 1983 (McLea 1986), which was later attributed to increased suspended solid concentrations and turbidity, that had substantially reduced light penetration depths within the watercolumn (for photosynthesis). The vegetation decline continued from this time, and submerged plant species were last reported from the lake in mid 1984 (Champion et al. 1993). Lake Ohinewai is currently de-vegetated and has been in this condition since at least 1991.

Lake Ohinewai's margin is now fully fenced to exclude stock. The fenced margin has also recently been extensively planted with native species. Prior to fencing and planting, the wetland and emergent zones of the lake had been heavily grazed and were dominated by willow and gypsywort (Wildland Consultants 2009). WRC contributed to the cost of c.1800m of fencing through the Clean Streams programme.

The lake is mostly steep sided[29] with a shallow littoral zone that drops away quickly to 2 metres depth (McLea 1986). A very narrow fringe of established trees and emergent vegetation occurs around most of the shoreline.

Lake Ohinewai is not identified in the WRP for lake level setting, despite having been substantially lowered. In 1981, the levels of the lake were reported to have been controlled by a weir across the outlet of the lake (Davenport 1981). It is unclear whether this weir remains in place today.

[29] a more gradual depth change occurs at the western end of the lake

The narrow width of the marginal fringe has restricted the amount of habitat available for birds to use, but shags, ducks, black swans, pukekos and white-faced heron are all likely to use the lake (Wildland Consultants 2009). DOC has recently fenced and planted along the lake margins, which should go some way to improving habitat for these and other bird species.

Native fish species are known from Lake Ohinewai, although the amount of habitat has been substantially reduced. Common bully and eels have been recorded from the lake in the past, and longfin eels and freshwater mussels occur in the lake (Wildland Consultants 2009, K. Neilson *pers. comm.*). Lake Ohinewai also contains a number of invasive fish species, including koi carp, brown bullhead catfish, goldfish and *Gambusia*.

The University of Waikato has recently undertaken an intensive research programme at Lake Ohinewai to test methods for mass removal of koi carp as a lake restoration tool. Various methods were trialled such as automated baited traps, one way fish barriers, electrofishing, fyke netting, and pod traps. Despite installing an effective koi carp barrier gate that allowed adult fish to leave (but not re-enter) Lake Ohinewai, and physical removal to fish densities of well below the target level of 100kg/ha, the programme did not reduce koi carp densities sufficiently to achieve submerged plant recovery, except in areas where koi carp were physically excluded (Dr Kevin Collier, Waikato University, *pers. comm.*). This research is in the final stages, and management agencies are currently considering whether further resources should be directed to maintaining the fish gate/barrier in the outlet of Lake Ohinewai, and continuing to harvest koi carp to reduce browsing pressure.

The poor condition of the lake is a result of multiple stressors operating at a large scale. Management options are limited by the scale of these issues, although the ecological condition of the lake could possibly be improved by: removing invasive freshwater fish; reducing nutrient loads (i.e. fencing inflows to reduce nitrogen and phosphorus concentrations); and installing a water level control structure to increase lake water levels. Establishing a formed public accessway to Lake Ohinewai within the recreation reserve administered by Waikato District Council and road reserve is also a high priority.

Options for management and acquisition of information:

- continue to monitor lake health indicators annually for the duration of the pest fish control project
- re-survey aquatic vegetation in the lake using Lake SPI if aquatic plants regenerate
- work with DOC to assess the future management requirements of the lake and surrounding reserve (which may include riparian management and weed control, invasive fish removal, increased water levels, reserve management options, improved public access)
- advocate for and support (where possible) actions to improve the future management of the lake and adjoining wetland
- support DOC to maintain pest fish control initiatives at the conclusion of the University of Waikato's research project
- work with landowners in the lake catchment (including Waikato District Council) to encourage best management practices on farms to reduce nutrient and sediment inputs to the lake.

4.2.5 Lake Okowhao

Depth	2.2 m
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Wildlife management reserve administered by Department of Conservation
Lake area	21 ha
Estimated catchment area	
Catchment land use	Dairy/Solid Energy coal mining
Percent native vegetation cover in catchment	4.5%
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✓
Identified as Priority 1 Stock Exclusion	✓

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (15)	WRC zone (29)
16	4	2	4
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Okowhao is a small, shallow lake located north of Huntly that forms part of the Okowhao drainage area. The lake receives water from drains that run through farmland to the south and south east of the lake. The lake outlet discharges to the Waikato River via an incised drain that runs east to west. The lake either discharges through a gravity fed culvert passing under Te Ohaaki Road, or water is pumped through another set of culverts during high flow events. Both of these sets of culverts have flapgates installed at the downstream end to prevent ingress of water from the Waikato River during high flows. An ephemeral oxbow area exists on the river floodplain below the outlet culverts that is inundated only during high flows.

Water quality sampling was undertaken in Lake Okowhao between January-March 1981 (Davenport 1981; Boswell *et al.* 1985). At this time the lake is reported to have been eutrophic. The water was peat stained but clear with good light penetration that created ideal conditions for submerged aquatic macrophytes (including *Egeria densa*). In 1986, secchi depth was estimated at 1.5m and light penetration was sufficient for submerged aquatic plants[30] to grow to a maximum depth of 2.2m (Clayton, in Garrick & Saunders 1986).

The water quality of Lake Okowhao was most recently sampled by Council staff between 2007 – 2010 as part of a project investigating indicators of shallow lake health. The water quality data from these surveys are presented in the table below, and the estimated TLI scores indicate that the lake is currently hypertrophic. Results from

[30] *Egeria densa* was the dominant submerged aquatic plant species

2007/2008 should be used with caution as the Waikato region experienced severe drought over the period of sample collection

	Mean SD (m)	Mean Chl *a* (mg m^3)	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
1981[a]	0.4-1.6	48	1029	53		6.7-8.7	2.6
1986[b]	1.5						
2007/2008[c]	0.675	31	1457	130	5.95	7.55	11.1
2008/2009[d]	0.472	65	1840	177	6.41	7.33	23.3
2009/2010[d]	0.568	58	1956	132	6.26	7.6	27

a Davenport (1981); WVA based on 10 samples taken between January and March 1981

b Clayton, in Garrick & Saunders 1986

c WRC shallow lake health indicators programme (December/March) (Neilson & Hamer 2008).

d WRC shallow lake health indicators programme (average of December, March, May samples)

Lake Okowhao was one of the last lakes in the lower Waikato River catchment to retain submerged aquatic plants. In 1991, *Egeria* formed dense surface-reaching beds that covered the entire water surface from the edge of marginal plant communities to a depth of 1.5m, and occupied up to 75% of the lake sediments. *Nitella hookeri* and *Potamogeton ochreatus* occurred in shallower waters at much lower densities and heights of less than 0.5m (Champion et. al. 1993). Submerged aquatic plants collapsed sometime after 1991, and a recent Lake SPI survey confirms that the lake remains de-vegetated (Edwards *et al.* 2010).

The lake margin is fully fenced and has been so for at least 20 years. However, approximately 100 m of fencing along the eastern boundary is of a poor standard and may not be stock proof, so this section is a high priority for repair or replacement.

The fenced lake margin is 20-100m wide. Native species (predominantly raupo, reeds and sedges) dominate the emergent vegetation zone of the lake although exotic plants are also common. The wetland zone comprises predominantly grey willow with a native understorey (Champion et al. 1993; Wildland Consultants 2009).

Boswell *et al.* (1995) reported that a great variety of wildfowl utilise the lake, including seasonally large numbers of swans. NZ dabchick and Australasian bittern, which are of conservation significance, have been recorded from the lake, and there is also an unconfirmed record of spotless crake from 1996. Moynihan (1986) also lists grey teal and marsh crake as having been recorded from the lake, and ranked the lake as a moderate-high value wetland site on the basis of its wildlife values.

The lake fishery is dominated by exotic species, including brown bullhead catfish, goldfish, and *Gambusia*. Koi carp have also been reported from the lake (Wildland Consultants 2009). Only 2 native fish species, eels and common bullies, have been recorded from the lake, despite its proximity to the Waikato River which supports a far more diverse native fishery. This reflects the poor connectivity (for fish passage) that exists between the river and Lake Okowhao, except during high flows. Fish passage between the river and the Lake Okowhau outlet drain is only available when sufficient rainfall has occurred within the lake catchment to generate flow in the drain capable of opening the flap-gate, and sufficient flows in the Waikato River to backfill the oxbow that the drain empties into. Unfortunately the lake and river are usually only connected in this manner at either end of the winter, which does not coincide with the migration timing of

some native fish species (eg elvers). Furthermore, even during these occasions, upstream migrants would encounter substantial water velocities at the culverts that are unlikely to be passable. Downstream passage is likely to be impeded at times by the pump when river levels are high (Wildland Consultants 2010a).

Lake Okowhao is in close proximity to the Huntly East underground coal mine. As part of these activities, coal mining access drives and related structures have been constructed under the lake bed, and groundwater is currently diverted from the area[31]. As a result, land subsidence is predicted to occur that will extend and deepen Lake Okowhao. This subsidence was predicted to occur before 2009, but depth sounding indicates that this has not occurred as yet. Any increase to the surface area of Lake Okowhao and extension of wetland areas is likely to be beneficial for the lake.

The main threats to the lake are the presence of exotic fish, nutrient and sediment inputs, and poor connectivity with the Waikato River. Lake Okowhao is in poor condition, yet it ranks highly amongst lakes of its type, and there are significant opportunities to improve its condition. Weed control and planting programmes could achieve a substantial improvement in the condition of marginal and emergent vegetation, whilst the removal of invasive fish may result in water quality improvements and assist with macrophyte regeneration.

A collaborative project has been initiated by Genesis Energy and Waahi Whaanui to enhance eel habitat and improve fish passage to the oxbow situated on the floodplain of the Waikato River, downstream of Lake Okowhao. Resolving fish passage issues for the lake itself is complicated by difficulty in predicting future subsidence levels from underground mining operations (Wildland Consultants 2010a).

Options for management and acquisition of information:

- monitor shallow lake health
- re-survey aquatic vegetation in the lake using Lake SPI if aquatic plants regenerate
- work with DOC, and other MOA agencies to assess the lake and its future management requirements
- advocate for and support where possible actions to improve the future management of the lake (including management and enhancement of riparian and emergent vegetation, weed control, invasive fish removal, and increasing water levels)
- work with other stakeholders to improve native fish passage to Lake Okowhao (taking into account future land subsidence)
- work with stakeholders to improve public access to the lake.

[31] Pumped to an underground settlement sump then discharged to the Kimihia Pit before final transfer to the Kimihia Wetland (Golder Associates 2009)

4.2.6 Lake Penewaka (Penewaka Lagoon)

Depth	1.0 m
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Lake Waikare wildlife management reserve (eastern side of Lake) and Lake Rotokawau conservation area – both administered by Department of Conservation
Lake area	4 ha
Estimated catchment area	Unknown
Catchment land use	Dairy/drystock
Percent native vegetation cover in catchment	Unknown
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✓ Part of the Lake Waikare complex
Identified as significant wetland (WRP Rule 3.7.7)	✓ Part of the Lake Waikare complex
Identified as Priority 1 stock exclusion	✓

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (17)	WRC zone (29)
19=	6=	3	6=
Figures in brackets indicate the total number of lakes included in assessment.			

This small lagoon and its surrounding 42 ha reserve are part of the Lake Waikare wetland and lake complex.

Lake Penewaka was included in the shallow lakes indicator programme in 2010/11 but holds no previous water quality information for the lake. The results are presented in the table below and indicate that the lake is extremely nutrient enriched (i.e. hypertrophic).

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
2010/2011[a]	0.25	53	3847	430	7.03	7.0	55.83
a WRC shallow lake health indicators programme (average of December, March, May samples)							

Lake Penewaka is known to dry up during drought years, and experiences periods when it is free of koi carp and catfish with reasonable water clarity (D Klee *pers. comm.*).

The lake margin has been extensively drained, and was grazed until 2003. The lake margin has now been fully fenced to exclude stock. The nationally endangered aquatic liverwort *Ricciocarpos natans* has been reported (but not confirmed) from wetlands in the lake margin (M. Lake, WRC, *pers. comm*.). Fernbird are also known to occur in these areas.

During 2004/05 Lake Penewaka was the subject of a restoration programme[32] carried out by Fish & Game NZ (Auckland/Waikato region), which included investigations of ground levels in the reserve, bund maintenance, blocking of drains and creation of wader bird habitat (Teal, 2005). This work was directed at re-establishing a preferred water level regime in the reserve and increasing the wetland extent and quality around Lake Waikare (Teal, 2005). Planting has also been carried out at Lake Penewaka since 2005 with funding from the Waikato Catchment Ecological Enhancement Trust (WCEET) and the Honda Tree Fund.

Options for management and acquisition of information:

- resurvey shallow lake health indicators
- work with DOC and Fish & Game (Auckland/Waikato region) to assess the lake and its future management requirements
- advocate for and support where possible actions to improve the future management of the lagoon/lake and its margins.

4.2.7 Lake Rotongaro

Depth	3.3 m
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Wildlife management reserve administered by Department of Conservation
Lake area	c. 292 ha
Estimated catchment area	1950 ha
Catchment land use	Dairy/drystock
Percent native vegetation cover in catchment	2.33%
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✓
Identified as Priority 1 stock exclusion	✓

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (15)	WRC zone (29)
22	8	4	8
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Rotongaro is a large shallow lake with a highly convoluted margin, few significant inflows and a single outflow which drains into Lake Rotongaroiti. The catchment is predominantly pastoral (*c.*1200 ha, 62%) with small areas of plantation pine forest.

[32] detailed in a Management Action Plan prepared by Fish & Game – Auckland/Waikato Region in 2004

Town (1982b) reported on water quality results from 10 (weekly) sampling visits to Lake Rotongaro undertaken between 5 January -10 March 1982. At that time, the lake was described as being a turbid light brown colour. During aquatic plant surveys in 1986, Clayton described the lake water quality as being poor with in water visibility of 200-300mm (in Garrick & Saunders 1986). Waikato Regional Council holds no more recent water quality data for Lake Rotongaro, although the lake is known to have suffered serious algal blooms in recent years.

	Mean SD (m)	Mean Chl *a* ($mg\ m^{-3}$)	Mean TN ($mg\ m^{-3}$)	Mean TP ($mg\ m^{-3}$)	Estimated TLI	pH	Turbidity (NTU)
1982[a]	0.1 - 0.3	19.7		104.2		7.1	
1986[b]	0.6						
a Town (1982b) weekly water quality sampling undertaken by WVA between January - March 1982 b Chapman (in Garrick & Saunders 1986)							

Little information is available about historic submerged plant communities of Lake Rotongaro (Champion et al. 1993). Aquatic plants were surveyed in 1986 and 1991 when the lake supported variable beds of *Egeria densa*, native turf communities and occasional beds of charophytes (Champion et al. 1993, Clayton (in Garrick & Saunders 1986). Champion et al. (1993) suggest that the submerged vegetation of Lake Rotongaro was reasonably static from the 1980's until the early 1990's, with *Egeria* beds restricted to shallow, sheltered bays. The lake did not support any submerged vegetation in 2005 when a full lake SPI assessment was last undertaken, and was described as turbid (Edwards et al. 2005).

Lake Rotongaro is identified as a Priority 1 stock exclusion water body in the WRP but is not currently fully fenced. Some of the existing fences are inadequate and do not represent legal boundaries, however all but a small section of the lake is now fenced to some degree. Marginal lake vegetation is rapidly recovering in recently fenced areas (Wildland Consultants 2011e). DOC has undertaken a small amount of riparian planting on the south eastern side of the lake in conjunction with one landowner.

Lake Rotongaro discharges through a short channel to Lake Rotongaroiti, which then flows through the Rotongaro canal and on into the Lake Whangape outlet via a floodgate structure before entering the Waikato River. Substantial outlet modifications have lowered the levels of lakes Rotongaro and Rotongaroiti. The Rotongaro canal dries up periodically during low flow periods (particularly when the Waikato River is low). As a result, there is no year-round connection between the river and the lake.

Lake Rotongaro is listed in section 3.7.7 of the WRP, so is subject to Rule 3.7.4.6. Under this rule, a resource consent is required to create new drains or deepen existing drains within 200m of the legal property boundary.

Wetland vegetation is present around the margins of Lake Rotongaro and in seasonally damp hollows within the catchment. Grey willow dominates large areas of the wetland vegetation, particularly in association with inflows, however, indigenous species are common beneath the willow, and are regenerating amongst adventive species where stock have been excluded. Manuka and broadleaved species scrub is located over relatively large areas on the north-western margin of the lake, and gorse shrubland is present in scattered clumps (Wildland Consultants 2011e).

An important manuka-dominated wetland (of c.19ha) occurs at the south-western corner of Lake Rotongaro, which ranks highly in terms of its ecological values, and meets the criteria for national importance (C Beard, unpublished WRC report). In 1999, the wetland was assessed as part of a project to prioritise areas in private tenure for pest control (Wildland Consultants & Epro 1999). Concern was expressed about the impact of grazing animals on the understorey, and the presence of willow and royal fern. While willow was recommended for control, royal fern was too widespread for control using conventional methods, and fencing was recommended as a high priority to protect the understorey.

The lake contains a range of fish species including catfish, eels, smelt, common bullies, *Gambusia*, and koi carp, and has been subject to commercial eel fishing in the past (Hayes in Garrick & Saunders 1986).

The lake has previously supported dense beds of freshwater mussels (*Echyridella menziesii* and *Echyridella websteri*) a rare and little known native mussel species that live beneath the sediment surface (Chapman in Garrick & Saunders 1986; Worthy & Whitehouse 1982). It is unclear whether these mussels still occur within the lake, given its current water quality.

The Department of Conservation recently commissioned a report on conservation values and the restoration potential of marginal areas within the wildlife management reserve that surrounds Lake Rotongaro and Rotongaroiti – significant areas of which are presently grazed and cropped. There are some significant conservation values as described above although grey willow, royal fern and reed sweetgrass are widespread throughout the reserve. There is significant potential to improve marginal habitat as the reserve provides a wide buffer around the lake (153 ha) of which 88.7 ha is currently pasture. Costs for re-vegetation, re-aligning fencing to the reserve boundary and undertaking weed control were estimated to be considerable, so were prioritised according to their values and restoration potential (Wildland Consultants 2011e).

A range of birds are known from Lake Rotongaro including Australasian bittern and New Zealand dabchick (Wildland Consultants 2009). Historically, fernbird are also known to have been present, and the lake also hosted one of the largest breeding colonies of little black shag that was known nationally (Garrick & Saunders 1986). The lake was ranked as a wetland site of moderate-high wildlife value in 1986 (Moynihan 1986).

The key threats to the lake are the presence of koi carp and other exotic fish, nutrient and sediment inputs from the very large pastoral catchment, poor riparian management and ongoing issues related to the lake's hydrological modification. The size and scale of the issues affecting the lake creates a difficult management prospect. However, substantial biodiversity benefits could be achieved in identified areas through riparian retirement, fencing, planting and weed control.

Options for management and acquisition of information:

- advocate for and support actions (where possible) to improve the future management of the lake (including riparian management and weed control and invasive fish removal)
- work with landowners in the lake catchment to encourage best management practices on farm
- support DOC to secure and improve public access to Lake Rotongaro
- assess lake levels and consider options to increase lake levels;
- survey lake health indicators.

4.2.8 Lake Rotongaroiti

Depth	0.5 m
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Wildlife management reserve administered by Department of Conservation
Lake area	c53 ha
Estimated catchment area	2105 ha
Catchment land use	Dairy
Percent native vegetation cover in catchment	2.27%
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✓ as part of same reserve as Lake Rotongaro which is listed under this rule
Identified as Priority 1 stock exclusion	✓

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (15)	WRC zone (29)
50	23	12	22
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Rotongaroiti is a moderately large and very shallow lake that is located adjacent to Lake Rotongaro. Because the lakes are inter-connected, Lake Rotongaroiti has previously been described as a secondary basin of Lake Rotongaro (Boswell *et al.* 1985). Lake Rotongaroiti lies adjacent to and is connected to Lake Rotongaro by a short channel (Champion et al; 1993).

The catchment is predominantly used for dairy farming, though small areas of plantation forest are present. The marginal vegetation of Lake Rotongaroiti is similar to that of Lake Rotongaro, with wetland vegetation predominantly confined to the margins of the lake, in seasonally damp hollows, and in association with inflows. Grey willow dominates large areas of marginal wetland vegetation; however indigenous species are common beneath the willow and are regenerating in areas that have been fenced from stock grazing (Wildland Consultants 2011d). As a result, there is considerable restoration potential at this site.

Lake Rotongaroiti was observed to be more turbid than Rotongaro when it was first formally investigated in 1986 (Garrick & Saunders 1986). A secchi depth of 0.4m was recorded when Chapman visited the lake in February 1986, whilst Clayton estimated in water visibility to be c.100mm (in Garrick & Saunders 1986). Waikato Regional Council holds no recent water quality data for Lake Rotongaroiti; although it can be assumed that the lake is highly degraded because of its extreme shallowness and water sources (Lake Rotongaro and the wider catchment).

In 1992, Lake Rotongaroiti supported the most well developed marginal turf community that NIWA observed during their vegetation surveys of Waikato lakes (Champion et al. 1993). Lake Rotongaroiti is the national stronghold for the sedge *Fimbristylis velata* (Wildland Consultants 2009).

In 1986, Lake Rotongaroiti was observed to support an almost identical suite of submerged aquatic plant species as Lake Rotongaro[33] except that the species grew to lower maximum depths. By 1992 submerged plants were extremely sparse with only 2 species represented as single plants (Champion et al. 1993). The most recent lake SPI survey undertaken by NIWA in 2005, confirmed that the lake did not support any submerged vegetation (Edwards et al. 2005).

Lake Rotongaroiti is identified as a Priority 1 stock exclusion water body in the WRP and while the lake margin is fenced, the fence is not located on the reserve boundary. Water sometimes floods above the fence line (Wildland Consultants 2011a). It is estimated that approximately 4000m of new fencing is required to exclude stock from the margins of the lake. DOC recently commissioned a report that identifies values and restoration options for land that it administers – an important component of which is grazed (Wildland Consultants 2011e).

Lake Rotongaroiti receives water from Lake Rotongaro and discharges to the Lake Whangape outlet via the Rotongaro canal, and then onto the Waikato River. Substantial outlet modifications have lowered the water level of Lake Rotongaroiti by over 1m during the last 15 years (Wildland Consultants 2009). The Rotongaro canal dries up periodically during low flow periods (particularly when the Waikato River is low). As a result, there is no year-round connection between the river and the lake.

There is little definitive information about the fish and bird species that utilise the lake, but it is likely that Lake Rotongaroiti supports a similar suite of species as Lake Rotongaro, including pest fish (koi carp, goldfish and mosquito fish). In 1986, the lake was ranked as a wetland site of moderate-high value for wildlife (Moynihan 1986).

The key threats to the lake are the presence of koi carp and other exotic fish, nutrient and sediment inputs from the very large catchment, poor riparian management and ongoing issues related to hydrological modification. Each of these issues occurs at a large scale and represents a significant barrier to in-lake restoration. However, substantial benefits could be achieved (as for Lake Rotongaro) through targeted riparian retirement, fencing, planting and weed control as described and costed by Wildland Consultants (2011e).

Options for management and acquisition of information:

- advocate for and support where possible actions to improve the future management of the lake (including riparian management and weed control)
- support (where possible) and advise landowners in the lake catchment to realign fences on to the legal boundary and increase the size of the riparian margin
- encourage best management practices on farms within the lake catchment to assist in the reduction of nutrients
- survey lake health indicators
- support DOC to secure public access to Lake Rotongaroiti (including boat access)
- assess lake levels and consider future options to increase water levels.

[33] including variable beds of *Egeria densa* and *Elodea canadensis* (both at less than 5% cover), native turf communities and occasional beds of charophytes

4.2.9 Te Otamanui Lagoon

Depth	Unknown
TA	Waikato District Council
WRC zone	Waipa
Land tenure	Unallocated crown land
Lake area	5.4 ha
Estimated catchment area	Unknown
Catchment land use	Unknown
Percent native vegetation cover in catchment	7.36 %
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (15)	WRC zone (15)
47=	20=	10=	13
Figures in brackets indicate the total number of lakes included in assessment.			

Te Otamanui lagoon is essentially a flooded gully that flows into the Waipa River near Te Kowhai. The lake is thought to have been formed when the Waikato River migrated and deposited alluvial and pumice material that dammed the valley (Te Kowhai Community Group 2009). The lagoon discharges via a c.1.5m culvert to the Otamanui Stream before it discharges to the Waipa River some 400m further downstream.

No water quality information is held by Waikato Regional Council for Te Otamanui Lagoon, but previous sampling was undertaken by Waikato University staff and students for Waipa County Council. The lagoon has is known to have poor water quality and be nutrient enriched (i.e. eutrophic). Historically, the lagoon has received dairy factory waste, effluent, and rubbish and has been described as being badly neglected (Te Kowhai Community Group 2009).

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
1977 [a]	0.49	28.7					
1988[c]	0.8	46	1300	205		7.7	
Chapman & Boubee (1977) b Page (1988) Mean of two samples taken between December 1987 to March 1988 – surface samples have been used for TP and TN							

The lagoon is divided into 2 distinct parts – an area of open water that extends up from the Waipa River/Bedford Road for about 700m which averages 100 -150m in width. The

narrower upper (mineralised wetland) reaches extend some 1.2km and are choked by willow with isolated kahikatea and cabbage trees that are periodically inundated (Te Kowhai Community Group 2009; Barnes 2001b). Grey willow was reported by Barnes (2001b) to form an almost complete canopy throughout the upper reaches of the wetland. In 1996, the lagoon was reported to have a maximum depth of 3m, have an open water area of 3.95 ha, and 11.2 ha of associated wetland (Cromarty & Scott 1996).

The lagoon is reported to support dense growths of nuisance aquatic plants that limit the amount of available open water habitat. In recent years, alligator weed has also existed at the lagoon. Ground based spraying was carried out 2-3 years ago, but alligator was re-found in late 2013 after willow cover was reduced. An aerial spraying operation was carried out in February 2014 with follow up (ground-based) undertaken in May 2014 (W. Mead, *pers. comm.).* Follow up work will also be undertaken in future.

Te Otamanui Lagoon is known to support a number of invasive fish species including koi carp, catfish and *Gambusi*. The Community Group undertook a fish survey in November 2013 (using fyke nets and gee minnow traps) which also confirmed the presence of shortfin and longfin eels, common bullies, inanga, and rudd in the lagoon. The eels captured were of good size and condition, although marae representatives have previously expressed concerns about the decline in native fish populations (including eels) within the lagoon (Barnes 2001b). Black mudfish have previously been recorded from the vicinity.

Mallard ducks, shoveler ducks and black swans have been reported from the lake in the past (Barea 1996), and marsh crake were heard during a recent visit to the lake in 2013 (M Lake WRC, pers*. comm.*). In 1979, the Wildlife Service cited bittern and banded rail as being present at the lake, but it is unknown whether they continue to exist there. Barea (1996) indicated that he considered that the habitat was sub-optimal for these species due to a lack of cover and water depths at the lagoon edge.

The lagoon receives surface water from surrounding land, but this is estimated to be about one half of the amount of water that the lake received historically. Around 1970, it appears that surface flows from the Te Rapa area[34] were diverted away from the lake which resulted in reduced amounts of flushing and the lake becoming stagnant (Te Kowhai Community Group 2009). The water level in the lagoon is thought reported to be controlled by a sill that is located approximately 10m upstream of the outlet culvert (Barea 1996).

The lagoon is unallocated Crown Land that is administered by LINZ, although other agencies (including DOC and possibly Waikato District Council) have expressed an interest in acquiring the lagoon in the past.

Te Otamanui Lagoon is not identified as a significant wetland in section 3.7.7 of the WRP so is not subject to drainage protection rules. It is also not identified as a priority stock exclusion water body. Barnes (2001b) reported that cattle have previously had access to the mineralised wetland and have grazed the understorey of the wetland. When WRC staff visited the site in September 2009, they observed that there was limited fencing at the northern end of the lagoon to exclude stock, and that riparian vegetation was absent from significant stretches of the riparian margin. The condition and extent of fencing around the lagoon is uncertain.

Te Otamanui Lagoon is the focus of a community project to establish a walking circuit for recreational use by Te Kowhai residents. The Te Kowhai Community Group project has focussed on establishing public access to and around the Lagoon. Willow control, land

[34] Approximately Hartstone Rd across to Brylynn Gardens Retirement Home area used to naturally flow south to Te Kowhai and entered at the head of the lagoon.

access arrangements and ultimately the restoration of the margins of the lagoon have also become increasingly linked to the project.

To date, the Group has created an accessway to the lagoon and undertaken several fencing and planting projects to facilitate and improve public access and enjoyment. The Group also recently undertook an aerial willow control programme in the middle section of the lagoon and around the open water areas in the lower lagoon. Options are now being assessed to remove dead willows, extend pathways around the lake margins, and expand the areas of open water habitat (T. Desmond, *pers. comm*.).

In 2001, Waikato Regional Council staff met with Waikato District Council staff and other parties to discuss the restoration options for Te Otamanui Lagoon. Four areas were identified for future attention – hydrology; invasive weed management; biodiversity of riparian margins; fishery values. Whilst Waikato Regional Council may be able to support some programmes at Te Otamanui Lagoon with advice and funding support, the site does not rank sufficiently high (in comparison to other projects) for WRC staff to lead a restoration programme at this site.

Options for management and acquisition of information:

- provide advice and support (including funding where possible) to the Community Group and landowners to improve the future management of Te Otamanui Lagoon (including fencing, riparian management, and weed control)
- encourage Waikato DC and DOC (or LINZ) to resolve land tenure issues at the lagoon and consider acquiring and retiring the margins of Te Otamanui lagoon
- survey lake health indicators
- consider including Te Otamanui Lagoon in the WRP for stock exclusion, lake level setting, and protection from future drainage.

4.2.10 Lake Waahi

Depth	5.0 m
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Reserve administered by Waikato District Council / private land Several wetland areas adjoining the lake – Waikato-Tainui (formerly DOC reserve)
Lake area	522 ha
Estimated catchment area	9221 ha
Catchment land use	Dairy/Drystock
Percent native vegetation cover in catchment	5.6%
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✓ 7.8m (Moturiki Datum)
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✓

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (15)	WRC zone (29)
12	3	1	3
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Waahi is the third largest lake in the Lower Waikato zone. The lake is situated to the west of Huntly township, within a predominantly pastoral catchment. The lake receives inflows from a range of sources including Awaroa Stream, and the much smaller Waikokowai Stream that drains into the north-western arm of the lake (Holland *et al.* 1987; Kingett 1984, Coal Corporation 1988). A coal haulage road was constructed across the north-western end of Lake Waahi in 1977 which has dissecting the north-west arm of the lake, and restricted water transfer between the arm and the main body of the lake.

The lake has played a significant role in commercial coal mining operations that have occurred within the area since 1876 – both as a water source for coal mining operations, and a receiving environment for mining-related discharges. Diffuse and direct discharges from coal mining have contributed large quantities of suspended sediments to Lake Waahi which have altered the colour, clarity and chemistry of the lake's water (Kingett 1984, WVA 1987). Coal mining was reportedly responsible for up to 90% of the sediment entering the lake at times (Dell 1988).

A great deal of information is held by Waikato Regional Council and other agencies about the water quality of Lake Waahi. It is understood that State Coal Mines monitored

lake water quality on a fortnightly basis at 3 sites between February 1976 - March 1979, but it has not been possible to locate these data.

Limnological surveys were undertaken by the University of Waikato during the summers of 1974/75 and 1975/76, when dense macrophytes extended over most of the lake, and stabilised the water column (preventing mixing and trapping sediment). In 1975, Chapman reported low water clarity (0.5-c.1.0m SD), and high chlorophyll *a* concentrations (c.30 – 80 mg m^{-3}) due to the presence of algae[35]. In 1976, water clarity is reported to have improved with SD of c.1.0 - 2.5m and chlorophyll *a* concentrations of c.5 - 20 mg m^{-3} (reported in Kingett 1984).

A significant shift in the lake water chemistry was observed after the aquatic vegetation collapsed in the lake in 1978/79 causing the (originally peat-stained) waters of the main body of the lake, to become highly turbid (Kingett 1984). The loss of aquatic macrophytes allowed water mixing and the lake water chemistry became more typical of an open water body. In 1981, the WVA observed that turbidity had little effect on phytoplankton growth, and that the low water clarity observed could not be attributed to chlorophyll a concentrations and phytoplankton abundance (Davenport *et al.* 1981; Kingett 1984; Boswell *et al.* 1985). Further studies indicated that this turbidity resulted from fine particulate matter (including Huntly fire-clays) derived from discharges from open cast mining operations that contributed to reduced light levels and the collapse of aquatic plants (Kingett 1984). A significant shift in the composition of phytoplankton communities also occurred, from green algal species dominance in the mid 1970s to a predominance of diatoms in 1981 (Coal Corporation 1988).

Waikato Regional Council has monitored the water quality of Lake Waahi every second month since September 1995. In addition, a lake monitoring buoy was installed in Lake Waahi in 2014 to collect real-time information about the physico-chemical conditions (and dynamics) within the lake.

The most recent monitoring results indicate that Lake Waahi is currently supertrophic, with low water clarity, high nutrient levels, and high phytoplankton density. Blue-green algae have also become abundant in recent years (Ryan et al., 2003; Hamilton *et al.* 2010). Analysis of recent data indicates that between 2006 and 2010 there has been a probable decline in the trophic state of Lake Waahi (WRC 2012). The table below summarises water quality information for the lake.

	Mean SD (m)	**Mean Chl *a* (mg m^{-3})**	**Mean TN (mg m^{-3})**	**Mean TP (mg m^{-3})**	**Estimated TLI**	**pH**	**Turbidity (NTU)**
1974/75[a]	0.2 – c.1.0		1205-1825 (TKN)	59-84			
1981[b]	0.2-0.3	53	744	105		7.4-8.4	25.8
1985/1986[c]	0.20 – 0.35	8 - 235		55 - 97			
1995-2001[d]	0.61	19.9	760	39	5.4		
2003-2007[e]	0.4	73	1860	80			
2006-2010[f]					5.9		
2006/2007[g]	0.33	97	1575	69	6.3	8.75	39.4
2007/2008[h]	0.63	22.7	1568	51	5.6	8	23.7

[35] a progression from green to blue-green algal dominance was observed through summer (Chapman 1981)

2008/2009[i]	0.24	38.3	1163	88	6.1	8.4	65.7
2009/2010[i]	0.46	23.8	1111	46	5.5	8.2	31.6
2010/2011i[j]	0.46	34	2494	68	6.03	8.4	63
2011/2012[i]	0.35	33	791	59	5.66	8.2	32
2012/2013[i]	0.16	48.3	1209	131	6.38		

a mean measurements obtained from sampling at 4 sites Dec 1974 - Feb 1975 (Chapman 1981).

b Davenport (1981); WVA based on 10 samples taken between January and March 1981

c WVA (1987) – median data provided for 5 sites in Lake Waahi (including NW arm)

d Average of samples taken between September 1995 and 2001- Barnes (2002a) – WRC data

e Waikato Regional Council data reported in Hamilton et al (2009)

f WRC shallow lakes water quality monitoring programme – bi-monthly samples. Data taken from Nutrient enrichment of shallow lakes State of the Environment Indicator: WRC (2012)

g WRC shallow lake health indicators programme (pilot study) (December, January and March) (Neilson *et al.* 2007).

H WRC shallow lake health indicators programme (December/March) Nielson & Hamer (2008)

i WRC shallow lake health indicators programme (December, January and March)

In 1974/75 Lake Waahi supported dense beds of submerged aquatic macrophytes[36], but by 1978 these had been reduced to isolated patches that were restricted to the shallow margins of the lake (Coal Corporation 1988). Reduced lake levels[37] that coincided with a pulse of sediment input from mining operations at this time are thought to have been responsible for the collapse of submerged aquatic macrophytes (Holland *et al.* 1987). Increased competition from phytoplankton, discharge of high concentrations of phenols into the Awaroa Stream in 1978, and intense grazing pressure from large populations of herbivorous black swans have also been implicated (WVA 1987, Kingett 1984).

In 1986, Clayton reported that submerged species were less abundant in Lake Waahi than in other nearby lakes, with a maximum cover of less than 5%, although a higher plant cover (of 5-25%) was recorded in the North-Western Arm (in Garrick & Saunders 1986). In 1988, *Egeria* plants were sparse and grew to depths of 1.2 and 0.7m in the main lake and NW arm, respectively. At this time, individual plants were healthy although plant cover was much less than 1% (Macaskill 1988).

During the most recent lake SPI survey in 2010, the lake was mostly de-vegetated and supported only sparse milfoil fringes (<5% cover) at depths of <0.3m (Edwards *et al.* 2010). This survey recorded a further decline in the extent of offshore stands of reeds (*Eleocharis sphacelata*). Poor aquatic plant regeneration levels have been attributed to the shallow nature of the lake, poor water clarity due to sediment re-suspension, and low levels of plant inocula (Kingett 1984, Champion et al. 1993).

When surveyed in 1993, the western shore of Lake Waahi had the most diverse amphibious lake turf community in the lower Waikato region, and it is likely that these features have been retained although they have not been monitored (Champion et al. 1993, Wildland Consultants 2009). Wetlands on the eastern and western sides of Lake Waahi have also been identified as some of the largest, unprotected examples of freshwater wetland vegetation of their types within the Meremere ecological districts (Wildland Consultants & Epro 1999).

[36] *Egeria densa* was the predominant species, although *Elodea canadensis* and *Lagarosiphon major* were present to a lesser extent (Chapman 1981).

[37] due to drought conditions and willow clearance from Waahi Stream that reduced lake levels by 0.2m in 1978/79

Lake Waahi is identified as a priority 1 waterbody for stock exclusion in the WRP, and fences have been constructed with funding contributions from WRC, Solid Energy, and private landowners to achieve stock exclusion (T. Balvert *pers. comm.*). Planting and fencing initiatives have also been undertaken as part of a collaborative project between Solid Energy, Waikato Regional Council, and private landowners, with additional funding support from WCEET. In total WRC has contributed to the costs of c. 9km of fencing at Lake Waahi (using soil conservation and Clean Streams Funding).

In 2011, the Waikato River Clean Up Trust provided c. $600,000 to Waikato-Tainui, Waahi Whaanui Trust and Genesis Energy to undertake a holistic restoration programme at Lake Waahi. The project had 3 aspects - riparian management/wetland enhancement, establishment of a community nursery, and control and management of koi carp.

Lake Waahi discharges to the Waikato River via the Waahi Stream, which contains floodgates at the lower end. These gates were installed in 1978[38] to protect the land surrounding the lake from the backflow of floodwater from the Waikato River. The gates have a maximum design lake level of 10.5m (Moturiki datum) (Dell et al. 1988). In 1986, following a public hearing of interested parties; a minimum lake level was set at 7.8m by the National Water & Soil Advisory Council (NWASCA). This minimum level is now incorporated into the Waikato Regional Plan[39].

Wells (1976) identified 12 fish species in Lake Waahi in summer 1974/75 including native[40] and exotic[41] species. A significant decline in common smelt abundance was measured between 1976 and 1981, during which time the lacustrine form became virtually extinct (Ward et al. 1987). This change was attributed at the time to the effects of dissolved and suspended substances upon egg and larval smelt survival (Town 1982b, Northcote & Chapman 1999). Black mudfish are also known to exist within the marginal wetlands surrounding Lake Waahi.

Koi carp and rudd are also now known to occur in Lake Waahi (reported in Wildland Consultants 2009), which will further limit the regeneration of aquatic macrophytes as a result of their feeding methods. Lake Waahi is also one of very few Waikato lakes that are known to support a significant population of European perch.

Eels have been commercially fished in the past, although the productivity of the fishery has declined significantly. The Lake Waahi eel fishery[42] is also culturally important, with an important traditional eeling site located on the Waahi outlet stream. The lake is classified as an Indigenous Fishery in the Waikato Regional Plan.

Fish passage has been an ongoing issue for Lake Waahi. A fish pass with velocity baffles was initially constructed to bypass the floodgate but this became impassable when Waikato River levels were low. Subsequently, a section of one of the flapgates was removed to provide an alternative fish access way, and a weir was constructed between the floodgate and the river to inundate the fish pass during low river flows (G Russell *pers. comm.*).

A total of 44 bird species have been recorded historically in and around Lake Waahi, including the threatened Australasian bittern, NZ scaup, NZ dabchick, North Island fernbird, and spotless crake (Kingett 1984; Moynihan 1986). The lake was ranked as a high value wetland site in 1986 when 22 wetland bird species were observed (Moynihan

[38] as part of the Waikato Flood Protection Scheme
[39] 3.2.4.7 Standards for maximum and minimum flows and levels
[40] Shortfinned and longfinned eels, giant kokopu, koaro, inanga, common bully, grey mullet, common smelt
[41] goldfish, mosquitofish, catfish, brown trout
[42] Focussed on migratory male eels (puhi)

1986); although it was acknowledged that bird numbers had markedly declined following the collapse of submerged macrophytes.

Lake Waahi has been considerably affected by nutrient and sediment inputs from the very large catchment, ongoing issues related to hydrological modification, riparian management, and the presence of exotic and invasive fish and plant species. The lake level has also been substantially reduced, and many of the surrounding wetlands have been converted to pasture for farming, which has contributed to the ecological changes that have occurred in the lake. Each of these issues occurs at a large scale and represents a significant barrier to in-lake restoration. However, substantial benefits could be achieved by undertaking planting and weed control within recently fenced lake margins. Fencing, weed control and pest control were also recommended for the future management and protection of the wetlands on the eastern and western sides of the lake.

Options for management and acquisition of information:

- continue to monitor lake water quality at Lake Waahi;
- maintain the real-time buoy to collect physico-chemical data from the lake, and use this information to assess future lake management options;
- re-survey the turf communities on the western shore of Lake Waahi to determine any changes since previous monitoring in 1993 and assess management options for them;
- provide advice and support (including funding where possible) to other agencies, stakeholders and landowners to undertaken fencing, weed control and pest control within the lake margin
- work with members of the MOA and others as required to assess and prioritise the lake's future management requirements
- re-survey submerged aquatic vegetation in the lake using Lake SPI at appropriate intervals.

4.2.11 Lake Waikare

Depth	1.8 m
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Lake bed administered by Waikato-Tainui
Lake area	3442 ha
Estimated catchment area	21,055 ha
Catchment land use	Dairy/drystock
Percent native vegetation cover in catchment	7.58%
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✓
Identified as significant wetland (WRP Rule 3.7.7)	✓
Identified as Priority 1 stock exclusion	✓

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (15)	WRC zone (29)
24	10	6	10
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Waikare is the largest lake in the lower Waikato catchment. The lakebed was previously administered by LINZ but has now been transferred to Waikato-Tainui through the Waikato River Settlement Act (2011) process.

Lake Waikare is located to the south-east of Te Kauwhata Township, and is connected to the Whangamarino wetland by the Pungarehu canal. The lake receives water from an extremely large catchment and discharges to the Whangamarino River and thenceforth to the Waikato River, via the artificial Pungarehu Canal. The lake is managed under a strict seasonal fluctuation regime of approximately 0.3 metres. Geothermal activity occurs on the eastern side of the lake, in and around Punikanae Rock.

Lake Waikare operates as a flood storage reservoir within the Lower Waikato Waipa Flood Control Scheme (LWWCS). Prior to the completion of the LWWCS in1965, Lake Waikare was part of an extensive hydraulically linked lake-wetland system that included lakes Kopuera, Ohinewai and Rotokawau, the Waikato River, and the Whangamarino wetland. During normal conditions water flowed from lake Waikare into the Waikato River through the Te Onetea Stream, although reverse flow occurred during flood events when the lake received water from the river via the Te Onetea and Rangiriri Streams and overland flow. High lake levels caused water to discharge from the lake into the Whangamarino wetland over the Te Kauwhata-Waerenga Road (Sledger 1980).

As part of the LWWCS, an outlet canal (with a radial flood gate) was constructed at the northern end of the lake (Northern Outlet) to convey water into the Whangamarino wetland. The Te Onetea and Rangiriri Streams were also blocked to prevent interchange between the lake and the Waikato River during normal flows. A culvert on the Te Onetea Stream is now opened to allow the Waikato River to flow into Lake Waikare.

As a result of these works, the average lake level was lowered by c.1m, and the lake level fluctuation range was reduced from 2.71m to 0.35m (Reeves et. al. 2002). Elimination of the natural seasonal fluctuation in water levels resulted in the loss of c.840 ha of seasonally inundated wetland that had previously linked lakes Waikare and Rotokawau, which was subsequently cleared and converted to pasture. It is estimated that the wetlands surrounding the shores of Lake Waikare have been reduced by 67% since 1963 (Reeves et al. 2002).

Water quality monitoring was initiated by the WVA in 1982, and Waikato Regional Council has monitored the water quality of Lake Waikare every second month between 1996 – 2012. The lake was also sampled[43] by Waikato Regional Council during the summers between 2007/08 – 2011/12 as part of a project investigating indicators of shallow lake health. Analysis of recent data indicates that between 2006 and 2010 there has been no significant change in the hypertrophic state of Lake Waikare which is extremely nutrient enriched (WRC 2012). Water quality information for Lake Waikare is summarised in the table below:

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
1982[a]	0.07 - 0.3	34.6		189.5		7.8	

[43] Sampling carried out in December, March & May

1994-1997 [b]	0.15	30.5	1202	161.8	6.28		
1998-2001	0.12	43.8	1436	245.3	6.62		
2002-2005	0.13	103	2414	371.3	7.19		
2006-2008	0.31	124	2836	209.3	6.90		
2003-2007[c]	0.3	100	2500	290			
2006-2010[d]					6.9		
2007/2008[e]	0.13	260	4851	400	7.7	8.75	150
2008/2009[f]	0.22	97.7	3649	203	6.99	9	69.7
2009/2010[f]	0.22	96.3	3268	167	6.88	8.1	68
2010/2011 [f]	0.5	71	3001	113	6.44	8.63	48.1
2011/2012 [f]	0.16	86	2315	161	6.8	8.1	57
2012/2013 [f]	0.20	90.3	2601	128	6.73		

a Town (1982b) weekly water quality sampling undertaken by WVA between January - March 1982

b Average of samples taken between January 1993 and 2001- Barnes (2002a) – WRC data

c 2003-2007 WRC data reported in Hamilton et al (2009)

d 2006-2010 W R C shallow lakes water quality monitoring programme – bi-monthly samples. Data taken from Nutrient enrichment of shallow lakes State of the Environment Indicator: WRC (2012)

e WRC shallow lake health indicators programme (December/March) Neilson & Hamer (2008)

f WRC shallow lake health indicators programme (average of December, March, May samples)

Lake Waikare has extremely high levels of suspended inorganic sediment that reduce light penetration into the water column. Aerial photographs from the 1940's indicate that the lake experienced increased turbidity during a time of extensive land clearance in the Matahuru catchment (Reeves et al. 2002). Anecdotal information suggests that this turbidity declined whenever the Waikato River flooded, indicating that the turbidity was locally derived and that inflowing Waikato River water had a flushing effect. However, the construction of the LWWCS prevented flushing, and the c.1m water level reduction would have increased wave velocities, thereby increasing sediment entrainment and turbidity within the water column (Reeves et al. 2002).

In 1982, the lake had high TP concentrations but relatively low chlorophyll *a* concentrations, indicating that algal production was limited by light availability or phosphorous absorption onto clay particles (Town 1982b; Boswell et al. 1985). Results between February 1993 and December 2001 were summarised and analysed by Barnes (2002a) who concluded that the lake had become eutrophic and that restoration would be problematic. Water quality monitoring since 2002 indicates that concentrations of phosphorus, nitrogen, and chlorophyll *a*, have further increased with a corresponding reduction in water clarity. The lake is presently hypertrophic, and blue-green algal blooms have become abundant in recent years. The Lake Waikare Steering Group (2007) reported that algal blooms are usually confined to isolated bays due to the influence of strong winds (Lake Waikare Steering Group 2007). Between 2010-2012, 90% of the 10 samples taken annually from Lake Waikare exceeded recreational guideline levels for blue green algae (WRC website 2014).

Most recently, Lake Waikare has experienced a red algal bloom which has been caused by a non-toxic microscopic algae, *Monoraphidium*. Cells have been present since May 2013, but reached considerable levels in June 2014 and became a source of considerable public concern (WRC website 2014)

An assessment of inflows indicates that the Matahuru catchment is the main source of

lake nutrients and sediment, contributing an estimated 60% of TN, 53% of TP, and c.75% of the annual sediment load[44] of the lake. The Te Kauwhata Sewage Treatment Plant[45] discharge was estimated to contribute 6-10% of the lake's phosphorus load and 1% of the lake's nitrogen load[46] before it was upgraded in 2006 (Lake Waikare Steering Group 2007).

The most recent lake SPI survey was conducted by NIWA in 2008 which confirmed that Lake Waikare remains de-vegetated (Edwards et al. 2009). The lake has been in this condition since the collapse of its submerged aquatic vegetation in the late 1970's (Champion et al. 1993).

Historically, Lake Waikare supported a range of aquatic plants[47], although submerged aquatic plants were comparatively less abundant in Lake Waikare than in other lakes in the lower Waikato region[48]. Between the late 1960's and 1977/78, substantial areas of Lake Waikare were covered in submerged vegetation, including *Egeria densa* (dominant) *and Myriophyllum triphyllum* (Champion et al. 1993). Since the collapse of submerged vegetation (documented by Williams) only sparse, low-growing plants have been recorded from restricted (sheltered) sites (Champion et al. 1993).

Reeves et. al. (2002) suggest that submerged vegetation is likely to have gradually declined since the 1940's due to decreased light penetration arising from increased turbidity and nutrient enrichment associated with land clearance, lake level reduction, and modification of wetland margins (including grazing). A phytoplankton bloom around 1977/78 is thought to have precipitated the final collapse of the (already stressed) submerged aquatic vegetation in the lake.

Regeneration of submerged vegetation is limited by a range of factors, including low water clarity due to the re-suspension of bottom sediments, and a high level of wind exposure that create an unsuitable environment for submerged plant regeneration (Champion et al. 1993, McLea 1986). Recent studies indicate that it would be difficult to increase water clarity due to the presence of (strongly light attenuating) fine clay particles that are unlikely to settle out of the water column naturally and high concentrations of algae and dissolved humic matter[49] that also attenuate light and limit the depth extent of submerged vegetation (Stephens & Ovenden 2003; Lake Waikare Steering Group 2007). The re-establishment of submerged vegetation is further impeded presence of plant damaging fish, a lack of plant inocula and blue-green algal scums (Reeves et al. 2002).

In recent years, DOC and Waikato Regional Council have undertaken weed control work for yellow flag iris and alligator weed in the vicinity of Lake Waikare under the provisions of the Biosecurity Act

Prior to 1965, a range of fish species were known from Lake Waikare, including eels, mullet, smelt, galaxiid species (including inanga and banded kokopu), bullies, shrimp, grey mullet, lamprey, and brown trout (Davenport 1980; McLea 1986). Nine species of fish were caught from the Lake Waikare catchment by McLea (1986) during surveys in 1983/84, including four native species (longfin eel, shortfin eel, smelt, common bully), and five introduced species (catfish, goldfish, mosquito fish, rainbow trout[50] and rudd). Black mudfish and banded kokopu have also been caught infrequently (Boswell et al. 1985). Black mudfish and fernbird are still known to occur within marginal wetlands, and

[44] amounting to 5400 tonnes of sediment per year
[45] The plant receives screened wastewater from Te Kauwhata township and Rangiriri village, leachate from a closed landfill nearby and wastewater from the Spring Hill Corrections Facility.
[46] Dependent upon calculation of mean discharge concentration or the 95 percentile concentration.
[47] Including abundant *Nitella hookeri*, *Ruppia polycarpa* and *Ranunculus limosella*, and scattered patches of *Isoetes kirkii,*
[48] attributed to the lake's mobile substrate (Kirk 1871)
[49] associated with swamp/bog drainage
[50] Trout were stocked into the Matahuru Stream up until c. 1981 by the Auckland Acclimitisation Society (Boswell 1985)

freshwater mussels *Echyridella menziesii* were reported from the lake in 2013 (M Lake, WRC, *pers. comm.*).

The construction of the northern control gates[51] as part of the LWWCS created a barrier to fish passage, although a small pipe system was created for climbing species (e.g. elvers). In 2003, a new rock-ramp fish pass was constructed to bypass the Lake Waikare control gate that provided for fish movement between Lake Waikare and the Pungarehu canal. During monitoring in 2003/04, twelve fish species were captured moving through the fish pass, including native and pest fish species (Boubee et. al. 2004). The presence and dominance of exotic fish (particularly koi carp, rudd and catfish) in Lake Waikare is of concern as these species are known to browse aquatic plants, disturb sediments and dislodge aquatic plants during feeding. Because they occur in such high densities within Lake Waikare, pest fish removal methods have been the focus of recent research and management initiatives.

In conjunction with other agencies and stakeholders, Waikato Regional Council has installed a permanent carp cage trap at the outlet of Lake Waikare in conjunction with the existing fish pass. The trap has been very successful to date and has removed 20-30 tonnes of fish over the last 2 years[52]. Once trapped, the pest fish are transferred into a bacterial digestor plant that is used to process the flesh of the fish into a dry granulated powder. Waikato Regional Council is investigating the use of this powder for plant fertiliser and other uses and considering options to install traps in a strategic manner within the lower Waikato basin (WRC website).

Lake Waikare was historically regarded as the most important lake eel fishery in the Waikato, returning up to 85 tonnes per annum. The eel fishery declined as a result of the hydrological changes associated with the LWWCS, but eventually stabilised at a new level that reflected reduced levels of recruitment and habitat/food availability. The fishery is mostly focussed on shortfinned eels, particularly migratory shortfinned eels that exit the lake to sea during February–April.

Lake Waikare is a significant area for water birds, although its habitat value has declined markedly since the collapse of submerged aquatic vegetation and the construction of the LWWFCS. In particular, major reductions in the abundance of black swans and large black shags were observed as a result of habitat changes and reduced food supplies (Reeves 2002; Davenport 1980; Greenwood 1997). Mallard numbers have remained high as the lake provides a daytime refuge for this species (Reeves et al. 2002). A number of species of conservation significance have been reported from the lake including white heron, Australasian bittern, and NZ dabchick (Wildland Consultants 2009).

Lake Waikare is identified as a priority 1 waterbody for stock exclusion in the WRP, but is not yet fully fenced, and a number of the existing fences are not positioned on legal boundaries. It is estimated that up to 20km of fencing may be required to fully protect the lake margin from stock access.

Work has recently been undertaken on Waikato Regional Council scheme land around Lake Waikare (on the northern side of the lake) as part of the Council's drainage consent mitigation requirements. This work has involved wetland creation and fencing of seeps.

[51] The northern outlet control gates created velocity and head differentials that were impassable to fish

[52] Mostly in operation October – February to co-incide with migration timing and flow events (and operating within the constraints of the resource consent conditions for the fish pass)

In 1980, the WVA[53] established an operating regime for Lake Waikare that provided for: (i) The Te Onetea gate to be opened to facilitate flow from the Waikato River; and (ii) seasonal operating water levels for Lake Waikare of:

- 5.50 m (Moturiki datum) for the period of 1 April – 30 September
- 5.65 m (Moturiki datum) for the period of 1 October – 31 December
- 5.60 m (Moturiki datum) for the period of 1 January – 31 March.

The most recent (2002) resource consents for the operation of the Lower Waikato Waipa Flood Control Scheme adopted these levels but provided for an operating range of ±0.1m around these levels. This flexibility recognises the control limitations associated with the use of the Northern control gates in the context of the size of the lake and its inflows, and the rate of water level changes that can occur. The sediment management conditions of the discharge consent associated with the operation of the LWWCS are currently being reviewed due to concerns about the sediment levels associated with the discharge, that are subsequently deposited in the internationally significant Whangamarino wetland.

The degraded condition of Lake Waikare is a result of hydrological modification associated with the ongoing operation of the LWWCS, point source discharges, non-point source agricultural discharges from the lake's wider catchment, and invasion by plant and animal pests. These issues occur at a large scale and combine to create a very complex restoration scenario. However, significant efforts have been made over the last 10 years to improve the condition of the lake. Waikato-Tainui has recently indicated that Lake Waikare will be their highest priority for future restoration and rehabilitation works.

As part of the resource consent and associated agreements for the ongoing operation of the LWWFCS, Waikato Regional Council was required to fence c.20km of the Matahuru Stream to reduce sediment inputs, and assess management options for the lake. A steering group[54] was formed to oversee this work, and over $180,000 was allocated between 2002-2004 for riparian management, and research and monitoring projects associated with the lake. A lake care group was established for Lake Waikare in 2007.

The Lake Waikare Steering Group assessed a range of management options that were considered to be infeasible, ineffective or cost-prohibitive - including lake water level drawdown, dredging, mussel biofiltration and flocculent treatment. However, the steering group recommended the following management actions and indicated that the proposed Waikato Lakes & Freshwater Wetlands Memorandum of Agreement Group could be a key vehicle for their implementation:

- improved riparian management (fencing of lake margins, reducing sediment inflows from Matahuru Stream, creation of wetlands around the lake margin);
- consideration of reserve designation for Lake Waikare;
- cessation of the sewage discharge into Lake Waikare;
- review the costs and benefits of a range of lake levels; and
- researching the following management options:
  - increased inflows from the Waikato River (through Te Onetea Stream);
  - trial management of the sheltered Western Bays using wave barriers to reduce wave action and encourage regeneration of submerged macrophytes;
  - reducing koi carp density; and
  - lake flushing.

[53] in 1979/80 NWASCO requested that the WVA set water levels for the lake through a public "lake level setting" process

[54] The vision of the Lake Waikare Steering Group is "*To restore Lake Waikare to a healthy stable ecosystem, supporting abundant plants and wildlife while providing a valuable flood storage role*"

In 2012, potential mitigation options for reducing sediment inputs to Lake Waikare and Whangamarino wetland were identified and assessed against a range of criteria (Wildland Consultants 2013). All of the mitigation options had significant drawbacks (e.g. extremely high costs, high uncertainty of outcomes, unacceptable to key stakeholders) and none of the options offered a single solution. The highest scoring option was to reduce sediment inputs from farms in the Matahuru and Waerenga catchments, followed by reducing peak flows from Lake Waikare and constructing a treatment wetland between Waikare and Whangamarino. The review identified critical gaps in knowledge including better quantification of (i) sediment and nutrient inputs and outputs, (ii) the extent of surface flooding at Whangamarino Wetland and (iii) the contribution pest fish make to suspended sediment levels in both Lake Waikare and Whangamarino Wetland.

Options for management and acquisition of information include:

- develop a multi-agency catchment management plan for the catchments of Lake Waikare and the Whangamarino wetland, including: upper catchment management (including fencing and soil conservation); riparian management; invasive fish control; weed management, and research trials for in-lake management and restoration
- continue to monitor water quality and shallow lake health indicators in Lake Waikare
- work with landowners within the catchment of Lake Waikare to inspect and maintain existing fences funded by WRC under land owner agreements
- re-survey submerged aquatic vegetation in Lake Waikare using Lake SPI if submerged plants show any indication of recovery
- work with MOA members to implement the recommendations of the Lake Waikare Steering Group and future catchment management plans
- continue to support initiatives to reduce point and non-point source discharges into Lake Waikare
- continue existing work programmes to prevent koi carp and other invasive fish from entering Lake Waikare during peak migration times, and investigate options to produce commercial products from the carp digestor at Lake Waikare
- work with members of the MOA and others to assess and prioritise the lake's future management requirements.

(NB. Issues linked with WRC's resource consents for the operation of the LWWFCS are excluded from the scope of this plan since they are funded and managed separately)

4.2.12 Lake Whangape

Depth	2.7 m
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Wildlife management reserve administered by Department of Conservation (including the adjoining Awaroa Wildlife Management Reserve).
Lake area	1450 ha
Estimated catchment area	31,767
Catchment land use	Dairy/drystock
Percent native vegetation cover in catchment	8.2%
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✓ 4.91m (Moturiki datum).
Identified as significant wetland (WRP Rule 3.7.7)	✓
Identified as Priority 1 stock exclusion	✓

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (15)	WRC zone (29)
23	9	5	9
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Whangape is the second largest lake in the Lower Waikato, which is associated with c.910 ha of marginal wetlands, including the Awaroa Swamp. The lake is situated within a large, predominantly pastoral catchment[55] and receives inflows via several streams, including the Waikokowai, Tikotiko, and Awaroa Streams. The lake is reported to have a short residence time of 1.5 – 2.5 months, and discharges into the Whangape Stream which joins the outlet from Lake Rotongaro before entering the Waikato River (Boswell et al. 1985, Vant, 1987).

The table below summarises available water quality information for Lake Whangape, which has been monitored by WRC since 2002. The information indicates that Lake Whangape is extremely nutrient enriched with very poor water quality. Analysis of recent data (between 2008 and 2012) suggests that there has been no significant change in the trophic state of Lake Whangape (WRC; 2014).

Most recently, Waikato Regional Council has also installed a lake monitoring buoy in Lake Whangape in 2014 to collect real-time information about the physico-chemical conditions and dynamics within the lake (WRC 2014).

[55] 78% sheep/beef and c. 9% dairy (July 2005)

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
1982[a]	0.5-1.5	12		25		9.9	
1992-1996[b]	0.54	24	864	72	5.69		
2003-2007[c]	0.3	130	2500	150			
2006-2010[d]					6.9		
2007/2008[e]	0.165	335	4551	240	7.52	7.75	104.5
2008/2009[f]	0.242	57	2064	142	6.49	8.17	58.7
2009/2010[f]	0.145	247	3985	202	7.37	7.9	137
2012/2013[f]	0.23	261	4390	143	7.19		

a Town (1982b) weekly water quality sampling undertaken by WVA between January - March 1982

b Average of samples taken between October 1995 and 2001- Barnes (2002a) – WRC data

c WRC data reported in Hamilton et al (2009)

d WRC shallow lakes water quality monitoring programme – bi-monthly samples. Data taken from Nutrient enrichment of shallow lakes State of the Environment Indicator: WRC (2012)

e WRC shallow lake health indicators programme (Neilson & Hamer 2008). (December and March)

f WRC shallow lake health indicators programme (average of December, March, May samples)

In 1982 Lake Whangape was the only large lake in the lower Waikato basin that still supported extensive aquatic plant beds. It was observed to have good water quality with low concentrations of suspended sediment, total phosphorous and chlorophyll *a*, although occasional algal scums were observed on the water surface (Boswell *et al.* 1985). During 1985/86 the water quality of the lake was studied as part of an investigation into the loss of submerged aquatic plants from the southern arm. At that time, the lake received high levels of suspended sediment from the catchment (point and non-point source inputs). The effects of mining inputs were particularly marked since they were largely confined to the arm during periods of low flow. At that time suspended sediment inputs from soil erosion were estimated at 7500 – 15000 tonnes yr^{-1} but did not appear to produce long periods of high turbidity in the lake, as most of this material was transported during flood events, and moved quickly through the lake as a result of its short residence time (Vant 1987).

Since that time, nutrient and phytoplankton concentrations have continued to increase, with a consequent reduction in water clarity and the overall condition of the lake. The lake has become increasingly eutrophic, and is now in a hyper-trophic state. Chlorophyll *a* concentrations are high, and blue-green algae have become abundant in recent years (Ryan et al., 2003; Hamilton et al. 2010). Between 2010-2012, 63% of the 10 samples taken annually from Lake Waikare exceeded recreational guideline levels for blue green algae (WRC website 2014).

The most recent Lake SPI survey (in 2005) confirms that Lake Whangape is currently de-vegetated (Edwards *et. al.* 2010). Historically, the lake was fully vegetated with a diverse assemblage of native submerged plant species, extensive raupo beds and flax/sedge swampland, and a native forest catchment (Champion et. al. 1993). Between 1958 and the mid 1980s, Lake Whangape was dominated by *Egeria densa*, although a marked decline in the abundance of submerged plants was observed within the southern arm of Lake Whangape between 1979 -1984[56]. High levels of inorganic suspensoids from mining discharges were directly implicated in the decline of aquatic plants within the southern arm (Town 1982a, Vant 1987, Wells et al. 1988).

[56] which may have been associated with the effects of mining discharges to the southern arm of the lake (Moynihan 1986)

Hornwort (*Ceratophyllum demersum*) was first identified in the lake in 1985, and rapidly replaced *Egeria densa* to become the dominant species when the submerged aquatic vegetation collapsed in winter 1987. Subsequently, hornwort re-established in sheltered areas[57] during the summer of 1987/88 and is reported to have formed surface reaching beds over much of lake (except the southern arm), before undergoing a further collapse between 2002-2005 (Champion et al. 1993, Champion et al. 1996, Champion et al. 2001a).

When surveyed in 1990, Lake Whangape was reported to have retained representative stands of many of the original vegetation types originally reported from the lake. Champion et al (1993) reported that the lake had the most diverse marginal vegetation of all of the lakes surveyed at that time in the lower Waikato catchment, although crack willow dominated the shoreline. A recent review of marginal vegetation at Lake Whangape found that it still retains representative stands of many of the original vegetation types, however grey willow, crack willow, and royal fern have had considerable impact on the diversity of many marginal plant communities (Wildland Consultants 2011b).

Almost 14km of the lake's shoreline supports significant amphibious turf communities during late summer/early autumn. A survey in 1997 documented 21 turf community types, that were highly diverse[58] and included the critically endangered grass *Amphibromous fluitans*[59]. The lake supports the largest known population of *Fimbristylis velata*[60], and regionally important populations of *Lobelia perpusilla*[61] and *Carex gaudichaudiana* (Champion et al. 2001a). The emergent plant zone is reported to contain mostly native species (Wildland Consultants 2009).

The Awaroa arm of Lake Whangape contains 32 ha of kahikatea forest making it the second largest area of seasonally-flooded kahikatea forest in the Waikato ecological region after Mangapu River Forest (52 ha). A recent survey of the kahikatea forest found it to be largely intact and is likely to persist for many years without management intervention, although opportunities for forest expansion are currently limited by the extent of grey willow forest in the vicinity (Wildland Consultants 2011b). Wildland Consultants (2012c) reported that the swamp kahikatea forest at Lake Whangape was the best within the Waikato district.

The pest plant, Alligator weed occurs at Lake Whangape and control work has been ongoing since 2002. The lake has been declared as a restricted place under the Biosecurity Act, which restricts the activities that can be undertaken to prevent further spread of alligator weed. Yellow flag has recently spread to Lake Whangape, including the upstream end of the Awaroa Arm posing a threat to marginal plant communities (Wildland Consultants 2011c).

Lake Whangape was identified as a wetland of outstanding value by Moynihan (1986) on the basis of its wildlife values. At that time the lake was a major waterfowl food resource, and was an important black swan breeding site and moulting site for NZ shoveler. A diverse array of bird species have been recorded from the site, including North Island fernbird, Australasian bittern, spotless crake, NZ dabchick, white heron and brown teal, which are of conservation significance (Moynihan 1986; Wildland Consultants 2009).

[57] including the Tikotiko arm and behind Motukauere Island
[58] comprising indigenous and alien species
[59] now thought to be extinct at the site
[60] Threat status = At Risk – Naturally Uncomon (de Lange et al. 2009).
[61] Ibid.

Fish population surveys were undertaken in the lake in 1986/87, 2000 and 2001 by Hayes (1989), West et al. (2000), and Chisnall et. al. (2007) respectively. In the most recent surveys, 11 fish species were captured from the lake, including 6 native species (shortfin & longfin eels, common bully, inanga, smelt and grey mullet) and 5 exotic species (*Gambusia*, catfish, goldfish, koi carp, and rudd). Black mudfish are also known to occur at the lake margins (M Lake, WRC, *pers. comm.*). Fish passage between the lake and the Waikato River is unimpeded when water levels are high, although West et al (2000) observed that passage may be affected when water levels are lower and water percolates through the rock rubble weir but does not flow over it.

The lake has been fished by commercial eel fishers in the past, and is reported to have produced a catch of 60 tonnes in 1982 (Boswell *et al.* 1985). Recent fish surveys show that eel populations that are now skewed towards individuals that are smaller than the minimum commercial size (220g). The Department of Conservation has indicated that commercial eel fishing will cease in future as the provisions of the Reserves Act are enforced within the Lake Whangape Wildlife Management Reserve (West *et al.* 2000). The Waikato River Clean Up Trust recently allocated $40,000 to a project aimed at improving the quality and production of eels in Lake Whangape.

Lake Whangape is identified as a priority 1 waterbody for stock exclusion in the WRP, but illegal grazing of the lake margins occurs regularly with considerable impacts upon the marginal vegetation, including recent plantings. It is estimated that only c.30% of the margin is fenced, and that up to 20km of fencing may be required to completely fence the lake margin. Waikato Regional Council has contributed to the costs of c.20 km of fencing (up until June 2006) under its Project Watershed and Clean Streams initiatives. A lake care group was established prior to this time (in 1998) that completed approximately 11.7 km of fencing and riparian planting on the shores of Lake Whangape. Many of these fences have temporary gates and it is evident that the lake margin is still being grazed by adjacent landowners (Wildland Consultants 2011a). In 2010 the Department of Conservation fenced the entire southern margin of the Tikotiko Arm effectively excluding all stock resulting in the regeneration of emergent macrophytes in this area. (Wildland Consultants 2011a).

The level of Lake Whangape has historically been at or above 5.0m (Moturiki datum). The natural sill at the outlet to the Whangape Stream was dug in 1989 and again in 1992, which reduced lake levels to 4.6m by 1993. A rock weir was constructed in 1993 by Waikato District Council in an attempt to recreate previous natural conditions. Further works were undertaken by Waikato Regional Council in 1999 to construct a weir in the Whangape Stream to reinstate lake levels to their lowest historical level of 4.91m (Moturiki datum). This minimum level has now been included in the WRP[62].

The degraded condition of Lake Whangape is a result of hydrological modification, non-point source agricultural discharges from the lake's wider catchment, riparian management, and invasion by plant and animal pests. These issues occur at a large scale and combine to create a difficult restoration scenario.

A recent assessment commissioned by the Department of Conservation assessed current vegetation and restoration potential of the Lake Whangape Wildlife Management Reserve (Wildland Consultants Ltd; 2011b). The report found that the reserve contained significant conservation values and provides habitat for at least 10 threatened species. The highest conservation values were present in the Tikotiko and Beverland Arms. Restoration potential was assessed for six sites surrounding the lake (ie Shuggs Landing, lake outlet, Beverland Arm, Southern Arm, Tikotiko Arm and 895 Glen Murray Rd). The Tikotiko and Southern Arms were considered to have the highest restoration

[62] Section 3.2.4.7 Standards for maximum and minimum flows and levels

potential. The costs to restore the Tikotiko Arm were estimated at $362,000 and involved fencing, weed control and planting to establish kahikatea forest and other wetland plant community types. The estimated cost for restoring the Southern Arm were estimated at $85,000 and involved fencing and weed control.

The viability of remnant charophyte seed banks has been studied to assess submerged vegetation restoration options. Charophyte oospores of five species were present at most sites at low densities[63] in the deeper sediment strata[64], making widespread natural charophyte re-establishment unlikely (de Winton & Clayton 1996; EWDOCS#1008096). Regeneration is likely to be further impeded by the presence of coarse fish in the lake, particularly koi carp and rudd which disturb sediments and feed on submerged aquatic vegetation (Champion et al. 2001a).

Champion et al. (2001a) recommended the following actions specifically for the future management of the turf communities present at Lake Whangape, although these need to be considered within a broader management context for the lake:

- lowering the existing outlet structure to provide more exposed surface for summer turf development;
- fencing larger areas of turf against cattle access;
- prevent cattle from accessing the entire shoreline of the lake;
- monitor the impact of waterfowl grazing on the turf communities;
- control expansion of willows and other weeds;
- trial fish exclosures for the impact on turfs; and
- attempt restoration of (specified) amphibious communities.

Options for management and information acquisition include:

- continue to monitor the water quality lake health indicators in Lake Whangape
- re-survey submerged aquatic vegetation in the lake using Lake SPI if plant regeneration is observed
- monitor the turf communities at Lake Whangape in conjunction with the Department of Conservation
- work with members of the MOA and others to assess and prioritise the lake's future management requirements and implement appropriate actions to address these
- support initiatives of other agencies and landowners (including funding where possible) to completely fence the margin of Lake Whangape to prevent stock access and undertake weed control
- assess the lake levels of Lake Whangape and consider options to improve fish passage at low flows.

[63] densities of 100-1000 seed per m^2 at most sites
[64] highest density at depths of c.20 cm.

4.2.13 Lake Opuatia (Unnamed 9)

Depth	Unknown
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Private land
Lake area	C6-7ha
Estimated catchment area	Unknown
Catchment land use	Dairy/drystock
Percent native vegetation cover in catchment	7.36%
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	Opuatia wetland
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (15)	WRC zone (29)
Data deficient	Data deficient	Data deficient	Data deficient
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Opuatia is a small privately owned lake situated north-west of Huntly on the northern margin of the Opuatia Peat Bog. The lake is located on the eastern side of the Opuatia Stream which discharges to the Waikato River near Churchill West. The lake has no inlet or outlet and is hydrologically connected to the Opuatia wetland that surrounds it.

Waikato Regional Council holds no water quality information about the lake, and there is little information about the lake's current ecological condition. The lake's water clarity was low and was described as being 'muddy' during marginal and submerged vegetation surveys undertaken in 1993 (Champion et al. 1993).

Despite its proximity to the peat bog, the lake's marginal and submerged vegetation are mostly of a riverine typology, although some peat influence was observed in the vegetation on the southern side of the lake (Champion et al. 1993).

It is unknown whether the lake still supports submerged aquatic vegetation. In 1993, the lake's submerged vegetation was dominated by pondweeds, *Potamogeton crispus* and *P.pectinatus*[65], with occasional charophytes (*Nitella hookeri* and *Chara corallina*). At that time, the lake was entirely surrounded by a willow dominated carr with a diverse range of understorey species, that extended to the Opuatia Stream on the northern and western sides of the lake. A large area of swamp meadow[66] was observed on the eastern margin

[65] This lake was the only lake that this species occurred in, although it was once far more widespread in the lakes of the lower Waikato region (Champion et al. 1993)

[66] A diverse mosaic of species with *Amphibromous fluitans, Triglochin striatum and Utricularia australis* occurring in pools amongst the vegetation

of the lake, whilst the southern margin contained a sedge community[67] that graded into low growing manuka scrub (with a dense *Carex*/*Baumeau* understorey). Emergent vegetation[68] was restricted to the eastern margins of the lake only (Champion et al. 1993).

The lake is likely to support a similar suite of birds as other lakes in the lower Waikato region, including the NZ dabchick, white heron, Australasian bittern, royal spoonbill, banded rail, marsh crake and NZ fernbird, which are of conservation significance and are known to occur in the neighbouring Opuatia wetland (Barnes et al. 2001). No information is available about fish species that occur in the lake, although black mudfish are known to occur nearby.

The lake has been visited since 1993 by several botanists, and a comprehensive list of vascular flora has been prepared for the area[69] that is based on 38 visits during 1982-2005. This list totals 454 species, including 276 indigenous, 176 naturalised and 2 planted species (de Lange, updated 2006).

Lake Opuatia is not identified as a priority waterbody for stock exclusion in the WRP, although it was one of few lakes where cattle had been excluded from the lake margin in 1993 (Champion et al. 1993).

The neighbouring Opuatia peat bog is one of five key restiad peat bogs that remain within the Waikato region, and is the focus of an active restoration programme (funded by Waikato Regional Council and WCEET) that has involved restoring groundwater levels[70], planting, fencing, weed control, and vertebrate pest control, (Barnes et al. 2001, Denyer 2007, Wildland Consultants 2011d). Whilst Lake Opuatia is part of the overall wetland complex, it is located on private land that is beyond the scope of the restoration project. As a result, little is known of its current condition and/or threats to it, although willow (crack[71] and grey) was well established on the lake margins in 1993 and royal fern was occasionally encountered, which may warrant management (if feasible).

Water levels in the wider Opuatia wetland (including Lake Opuatia) are strongly correlated with Waikato River levels. As a result, lake levels are likely to have dropped considerably over the last 40-50 years as a result of declining river levels associated with flood control, power generation, and sand dredging activities. River levels at Mercer have declined by some 1.3m since 1965 (Barnes *et al.* 2001).

Because there is insufficient information to rank that lake for its current biodiversity values, it is a priority to visit Lake Opuatia and assess its current condition and management requirements.

Options for management and acquisition of information:

- seek approval to visit Lake Opuatia to assess the lake and its future management requirements
- collect relevant information to enable Lake Opuatia to be scored using the 'Methodology for ranking lake ecosystems for lake ecosystems for biodiversity management in the Waikato region' to enable its inclusion in the SNA Lake Ecosystems assessment
- survey lake health indicators.

[67] Swards of *Carex* species, flax, Maru/burr-reed (*Sparganium subglobosum*)
[68] Raupo and *Bolboschoenus fluviatalis*
[69] in the main wetland system, wet pasture on adjacent farmland, Lake Opuatia, and the willow carr extending to the Opuatia Stream
[70] via the construction of a bund
[71] NB. crack willow was observed to have declined in 2005 due to defoliation by sawfly (Brown et al. 2005)

4.3 Waipa district

4.3.1 Lake Te Koutu (also Te Ko Utu)

Depth	1.5m (maximum)
TA	Waipa District Council
WRC zone	Central Waikato
Land tenure	Recreation reserve administered by district council
Lake area	6 ha
Estimated catchment area	416 ha
Catchment land use	Urban
Percent native vegetation cover in catchment	4.07%
Applicable joint agency accord/MOA	Waipa Peat Lakes Accord
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 Stock Exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (17)	Lake type (15)	WRC zone (7)
52	17	13	7
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Te Koutu is an urban lake that is located within a 17.6ha recreation reserve in Cambridge that receives a high level of passive recreational use. The lake is situated in an old oxbow of the Waikato River that was created when the Waikato River flowed down the Karapiro stream. Eutrophication of the lake has occurred as a result of urbanisation, and the lake receives high sediment and nutrient loadings from urban stormwater drains and diffuse seepage. The lake is now piped out to Karapiro stream.

The WVA studied the water quality of Lake Te Koutu between 5 January -10 March 1982 when the lake was observed to be nutrient enriched, and to become turbid and green in colour due to high algal biomass (Boswell et al 1985). Lake Te Koutu was also observed to stratify during this study despite being very shallow, which may have resulted in nutrient being released from the sediments. Winter water samples (taken in August 1981) indicated that the lake had poor water clarity year round.

The water quality of Lake Te Koutu was studied by Hoare in 1993 who reported that the in-lake concentrations of TP were elevated (to concentrations of 710 mg m^{-3}) after rain (reported in Singleton, 1997)

Water quality sampling undertaken between May 2003 - March 2004 by Waikato Regional Council indicates that some improvement in the water quality of the lake was achieved, although the lake was still hypertrophic. Waikato Regional Council does not hold any more recent water quality data for the lake, although it is known to have been

phytoplankton dominated for many years, and to have suffered significant algal blooms and water quality issues that have made it unsuitable for contact recreation.

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
1981[a]	0.1 - 0.4m	213	3291	304		8.0-9.3	32
2003/2004[b]	0.93	54.8	1118	108			
a Davenport (1981); WVA based on 10 samples taken between January and March 1981 b Waikato Regional Council data							

In 1997, Lake Te Koutu is reported to have supported stands of rushes and raupo, but no submerged macrophytes (Singleton 1997).

The lake is not identified as a priority stock exclusion waterbody in the WRP as stock access is not an issue for the lake. The lakes lies within an urban area and no stock are present,

Several fish species have been introduced to the lake, including golden carp and American catfish in 1887. The lake is now known to support goldfish, catfish and eels, and possibly also perch and tench. Fish densities were found to be high when the lake was lowered in the past (Singleton 1997). The lake is also utilised by waterfowl, although numbers were reported to fluctuate considerably in the past, with dramatic increases during duck shooting season (Davenport 1981).

The banks of Lake Te Koutu are well vegetated with shrubs and trees that were planted as early as 1906. In 2005, water lilies (*Nymphaea spp.*), rushes and irises were observed to have greatly reduced the amount of open water at the western end of the lake, to reach levels requiring management (Tonkin & Taylor 2005). Since then, Manchurian Wild Rice was identified growing at the lake, and was controlled[72] in 2008 by Waikato Regional Council.

The main threat to the lake is eutrophication through internal and external nutrient enrichment. Various management options have been assessed over the last 20 years, including stormwater diversion and sediment removal/dredging to reduce nutrients, and lake dilution/flushing (with groundwater) and or biomanipulation to reduce phytoplankton biomass (Singleton 1997). More recently, Tonkin & Taylor (2005) have suggested a range of actions to improve stormwater management, including at source controls (e.g. education, street sweeping, gross litter controls), end of line devices (e.g. separators and/or litter traps), and soft treatment options (e.g. constructed wetlands for stormwater treatment, and/or diversion of stormwater inflows from the lake). Various other options have also been considered, including lake edge improvements, septic tank reticulation (for properties north of the lake), and duck population control.

Several options have been tested, including initiatives to increase dissolved oxygen concentrations (using a boat motor and drum cage rotor), reduce nutrient levels (by lowering winter lake levels for flushing), and reduce algal biomass using barley straw (Singleton 1997). Approval was also obtained to introduce (caged) silver carp to the lake for algal control, but these fish were never released.

Improvement of the lake's water quality remains a high priority for Waipa District Council. The Council is currently working to improve stormwater inflows and the outflow from the lake (including the outfall to Karapiro Stream).

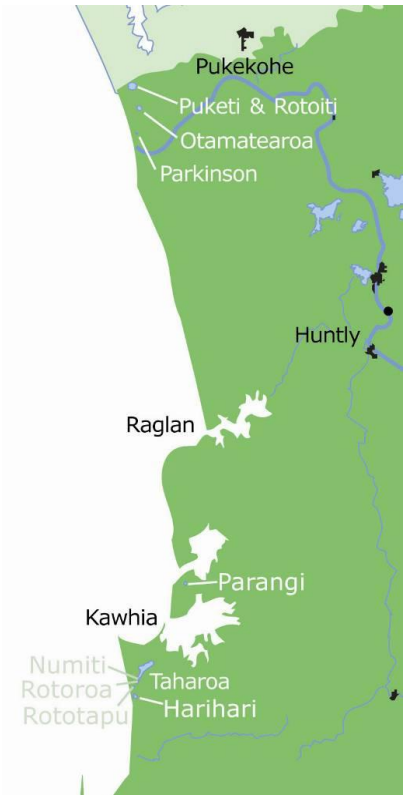
[72] as part of a small scale eradication programme

Options for management and acquisition of information:

- encourage and support Waipa District Council to improve stormwater management to reduce inputs to Lake Te Koutu
- encourage Waipa District Council to monitor the water quality of Lake Te Koutu.

5 Waikato dune lakes

There are 14 known dune lakes in the Waikato region[73] that are situated in the Waikato, Otorohanga and Waitomo districts. These lakes are mostly small to moderate in size (0.2 – 22.4 ha) with small catchment sizes (<134 ha), with the exception of Lake Taharoa (216 ha) and the other Taharoa (including Lakes Taharoa, Numiti and Rotoroa) that have a combined catchment area of 4226 ha.



Sand dune lakes are formed by wind-blown sand deposits that block valleys or depressions to create impoundments (Viner 1987). Dune lakes are most commonly found on the West Coast of the North Island, and formed, often in conjunction with peat swamps, between dune belts in the late Holocene.

Most dune lakes in the North Island are thought to have formed less than c. 5000 years old, although the dune lakes in the Kawhia-Aotea Harbour area (e.g. Lakes Parangi, Rotoroa, Rototapu, Harihari, Numiti, and Taharoa) are thought to have formed c. 50,000 years ago (Viner 1987).

As a group there is less known about the dune lakes in the region than any other lake types. Nine of the known dune lakes (Lakes Waitamoumou, Puketi, Rotoiti, Unnamed 3, Numiti, Piopio, Rotoroa, Rototapu, Te Rotopupu) did not have sufficient information overall to rank them for biodiversity management so were identified as data deficient[74] (Wildland Consultants 2011a). To address some of these gaps, Waikato Regional Council undertook surveys of some of these data deficient lakes in May 2014.

Figure 8 shows known and estimated scores for different aspects of the lake prioritisation method (described in Wildland Consultants 2011a) for known and suspected dune lakes. In several instances, scoring is based on best estimates, whilst no scores are provided for lakes that were completely unknown.

[73] Lake Te Rotopupu is also likely (but not confirmed) to be a dune lake, so has been included in this section
[74] Lakes with more than 5 criteria that had to be estimated or couldn't be scored

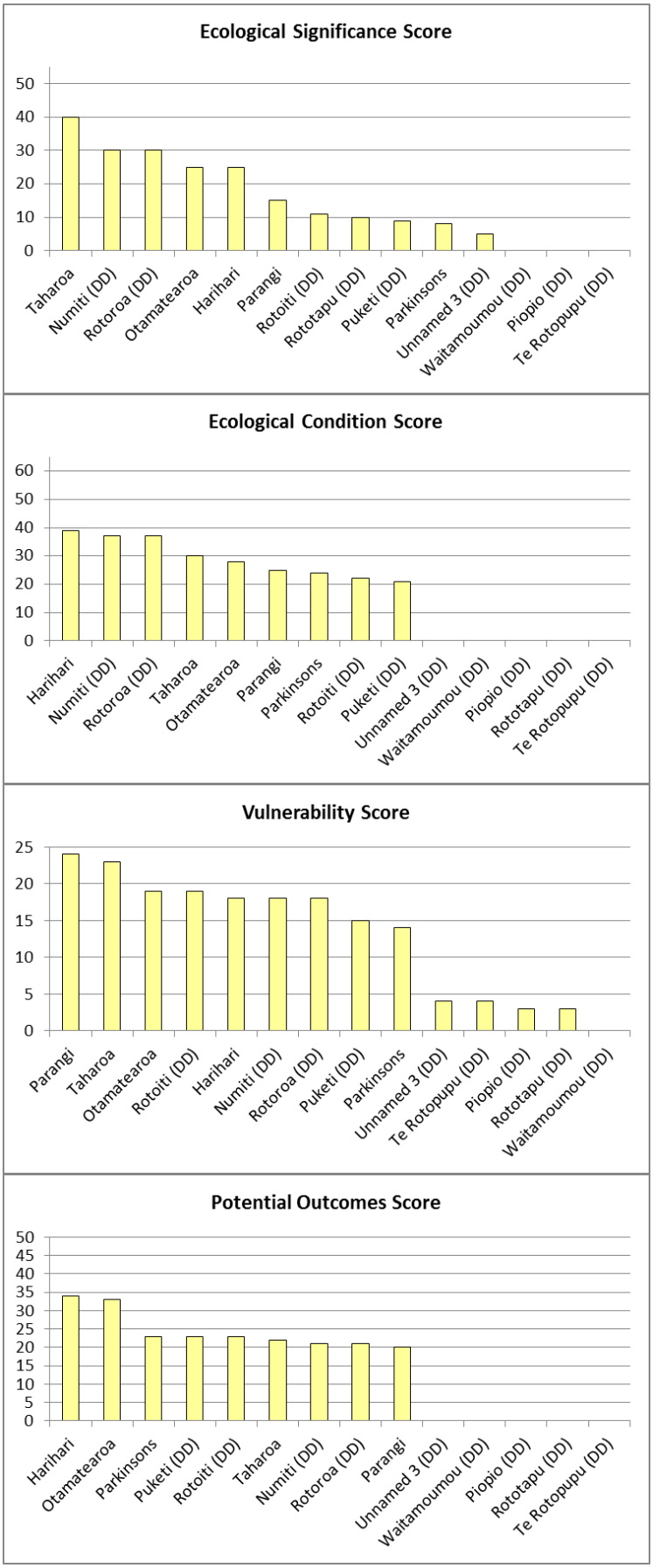


Figure 8 **Dune lake scores (including best estimates) for different aspects of the lake prioritisation method used to rank lakes in the Waikato region (Wildland Consultants 2011a)**

The Taharoa lakes, Lake Harihari and Lake Otamatearoa have the highest ecological significance and condition scores but also score highly for vulnerability.

All dune lakes, with sufficient data to enable scoring, have moderate to high scores for restoration potential. This can be partly attributed to all surveyed dune lakes containing submerged plant communities, which are worthy of protection since they may be very difficult to re-establish once they have collapsed.

5.1 Otorohanga district

5.1.1 Lake Parangi

Depth	16 m
TA	Otorohanga District Council
WRC zone	West Coast
Land tenure	Private land
Lake area	12.2 ha
Estimated catchment area	122 ha
Catchment land use	Drystock
Percent native vegetation cover in catchment	1.78%
Applicable joint agency accord/MOA	✕
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (3)	Lake type (14)	WRC zone (11)
13=	2	4	4
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Parangi is located on the West Coast and lies between Kawhia and Aotea harbours in a primarily pastoral catchment.

Lake Parangi was sampled by Waikato Regional Council in December 2007 and March 2008 as part of a project investigating indicators of shallow lake health. Water quality was poor and the lake was assessed as being supertrophic (Neilson & Hamer 2008).

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
2007/2008[a]	0.83	47	1431	63	5.8	9.1	22.9
a WRC shallow lake health indicators programme (December/March) (Neilson and Hamer: 2008)							

Studies of zooplankton communities in 2007/08 also predicted the lake to be supertrophic, with a rotifer inferred TLI of 5.0 (Duggan 2008). The farm manager reports that lake water quality has declined in recent years, resulting in algal blooms during summer

Submerged vegetation surveys in 2008 found that *Elodea canadensis* formed an invasive weed bed around the lake to a maximum depth of 3.6m, although several native species (including *Potamogeton ochreatus* and *Myriophyllum triphyllum)* were also recorded (Edwards *et al.* 2008).

Lake Parangi is not identified as a priority water body for stock exclusion in the WRP, although some of the lake's riparian margin remains unfenced. In 2007/08, 1760 m of 2 wire electric fencing was completed to create a riparian margin with an average width of c. 25m. In 2009, an additional 360m of 2 wire fence was completed and planted. A subdivision has recently been completed which included the provision for the creation of a 20m esplanade reserve around the lake margin. Fencing of this (c. 230m) remaining margin is required as part of the subdivision consent process. It is unknown as to what stage this is currently at however once completed will provide the entire lake with a stock proof margin.

Native freshwater eels and mussels are known to occur in Lake Parangi, along with the invasive brown bullhead catfish which is reported to occur in low density (Wildland Consultants 2009). Moynihan (1986) ranked the lake as a wetland site of moderate-high value for wildlife, on the basis that spotless crake, black shag and little shag were known to utilise the lake, and that waterfowl and little shag breeding occurred there at that time

The ongoing presence of submerged vegetation in Lake Parangi is threatened by its declining water quality. This may be addressed to some extent by the completion of riparian fencing but will also require improved riparian and land management in future.

Options for management and acquisition of information:

- resurvey lake health indicators
- resurvey submerged plants using Lake SPI
- work with landowners in the lake catchment to encourage best land management practices to reduce the impact of farm activities on the lake
- work with landowners to improve the management of lake margins (including targeted weed control and planting).

5.1.2 Lake Te Rotopupu

Depth	
TA	Otorohanga District Council
WRC zone	West Coast
Land tenure	Private land
Lake area	0.95 ha
Estimated catchment area	240
Catchment land use	Drystock
Percent native vegetation cover in catchment	4.94
Applicable joint agency accord/MOA	✕
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (3)	Lake type (14)	WRC zone (11)
Data deficient	Data deficient	Data deficient	Data deficient
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Te Rotopupu is a privately owned lake that is located on the West Coast of the Waikato Region near Kawhia Harbour.

It is not known whether the lake margin is fenced to prevent stock access. The lake itself is not identified as a priority water body for stock exclusion in the WRP, but its main inflowing and outflowing streams are identified for stock exclusion.

Because so little is known about the condition and values of Lake Te Rotopupu, it is a priority to visit and assess its condition and future management requirements.

Options for management and acquisition of information:

- seek approval from the landowners to visit this lake to assess its condition and future management requirements
- collect relevant information to enable this lake to be scored using the 'Methodology for ranking lake ecosystems for lake ecosystems for biodiversity management in the Waikato region' to enable its inclusion in the SNA Lake Ecosystems assessment
- work with landowners in the lake catchment to encourage best management practices.

5.2 Waikato district

5.2.1 Lake Otamatearoa

Depth	5.0 m
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Crown owned lake bed[75]
Lake area	4.9 ha
Estimated catchment area	68.30 ha
Catchment land use	Drystock/dairy
Percent native vegetation cover in catchment	0%
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (14)	WRC zone (29)
7	1	3	1
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Otamatearoa is located in the north west of the region and is a small, relatively deep lake.

Lake Otamatearoa is one of very few shallow lakes in the region that are known to have oligo-mesotrophic water quality, and good clarity. Based on the 4 periods of sampling undertaken by Waikato Regional Council between 2006 and 2011 the mean TLI of the three sampling occurrences is 3.48 which indicates a mesotrophic state. Water quality data is summarised in the table below.

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
2006/2007[a]	2.97	1.5	325	10	3.4	8.5	1.1
2008/2009[b]	3.08	1.5	322	6.67	3.28	8.03	1.19
2009[c]	>3.5		270	5			
2009/2010[b]	3.27	1	711	11	3.70	8.1	2.5
2010/2011[b]	3.4	1	538	10	3.57	8.66	1.50
a WRC shallow lake health indicators programme (pilot study) (December, January and March) (Neilson *et al.* 2007).							

[75] LINZ unallocated Crown Land with riparian (water-use) rights vested in adjoining private land owners

b WRC shallow lake health indicators programme (average of December, March, May samples)
c Waikato University Sampling 28 April 2009 – B.Hicks pers. comm.

Significantly, the chlorophyll *a* concentrations are within the range expected for oligotrophic lakes. Investigations of zooplankton communities in 2006 predicted the lake to be eutrophic using the rotifer inferred trophic level index (Duggan 2007).

Surveys of submerged vegetation conducted in 1996, 2004 and 2009 showed a decline in the condition of the native plant assemblages within the lake, as a result of the introduction of *Elodea canadensis* some time before 1950, and the introduction of hornwort (*Ceratophyllum demersum*) sometime after 1996. Hornwort has expanded to form extensive beds since 1996 which has had a significant impact upon submerged native plants in the lake. Some native charophytes remain in the lake, although the Lake SPI index has declined from 39% to 18% between in 1996-2009 (Edwards *et al.* 2009).

To address the impacts of hornwort on the lake's water quality and biodiversity values, NIWA and Waikato Regional Council attempted an eradication operation in September 2009 using Endothall (Aquathol K). Monitoring two months after the trial was initially promising with a 95% reduction of hornwort biomass and extensive charophyte recovery. However, hornwort re-grew to completely cover the western end of the lake (up to 2m tall) and partially cover (c.25%) the north eastern end of the lake (R Wells *pers. comm.*). A further survey of submerged vegetation in 2010 indicated an improvement in condition of the native plant assemblages in the lake following the Endothall application, although these were not sustained following the recovery of hornwort (Edwards et al; 2010). In June 2011, NIWA returned to the lake and applied 3 treatments of Endothall at higher concentrations over a two week period. Follow up monitoring indicated that a few viable hornwort fragments had survived within the bottom sediments, so lake-wide eradication was not achieved and hornwort can be expected to expand to dominate the submerged vegetation (R Wells, *pers. comm.*).

Lake Otamatearoa is not identified as a priority water body for stock exclusion under the WRP. The lake is presently unfenced and stock has access to the lake margins. It appears that the catchment landuse has recently changed (c. 2010) from sheep and beef (drystock) to dairy farming so stock exclusion from the lake margin is a matter of priority.

Various threatened native plants are known from the lake and its margins. *Ranunculus macropus*, *Utricularia australis,* and *Myriophyllum robustum* have been recorded amongst emergent vegetation around the lake margin (Edwards et al. 2009). *Potamogeton ochreatus* and *Glossostigma elatinoides* have also been translocated to the lake by DOC (Benham 2008). Because of the risk of cattle damage to the lake margin, the lake's high water quality, and the presence of threatened species around the lake margin, fencing is an urgent requirement at this site and consideration should be given to retiring and restoring a substantial margin to reduce sediment and nutrient losses to the lake. Ongoing weed control will likely be required to control kikuyu and maintain marginal species diversity within the lake margin. Benham (2008) reported that the landowners had also undertaken some grey willow control within the lake margin.

The lake was electric fished by the University of Waikato in April 2009 (Hicks & Brijs 2009). Large shortfinned eels and common bullies were caught. It is thought that the eels are likely to have been stocked to the lake for commercial or recreational fishing. Two catfish, occasional rainbow trout and moderate numbers of goldfish were also recorded during this visit (B.Hicks *pers. comm.)*. Rainbow and brown trout have been stocked in the lake by the Fish & Game but it is unclear whether future introductions are planned. It is unknown whether *Gambusia* occur in Lake Otamatearoa, but they are known from other lakes in the vicinity.

No other oxygen weeds (e.g. *Egeria densa*) or Alligator weed (*Alternanthera philoxeroides*) occur in Lake Otamatearoa, although the lake may be at risk due to its proximity to other infestations.

The key threats to the lake are water quality deterioration through poor riparian management, displacement of submerged native plant communities by hornwort, the (accidental or purposeful) introduction of other invasive species, and the risk of complete vegetation collapse occurring in the lake.

Options for management and acquisition of information:

- review the status of hornwort and consider future eradication options in conjunction with NIWA researchers.
- support public education initiatives to minimise the risk of alligator weed and/or other oxygen weeds being transferred from nearby lakes
- monitor lake health indicators, including Lake SPI
- work with landowners in the lake catchment to encourage best management practices to reduce sediment and nutrient inputs to Lake Otamatearoa (including improved management of the lake margins)
- discuss fencing options with adjoining landowners to exclude stock from the entire lake margin and support where possible.

5.2.2 Lake Parkinson (Kohahuake)

Depth	6.0 m
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Private land
Lake area	1.9 ha
Estimated catchment area	107.72 ha
Catchment land use	Drystock
Percent native vegetation cover in catchment	1.09%
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (14)	WRC zone (29)
25	11	5	11
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Parkinson is a very small lake in a pastoral catchment, with an area of wetland on one arm. Waikato Regional Council holds no recent water quality information for Lake Parkinson but water quality sampling was undertaken at Whiriwhiri Road between March

1988 –February 1989. Recent anecdotal information suggests that the lake is becoming eutrophic (Benham 2008).

	Mean SD (m)	Mean Chl *a* ($mg\ m^{-3}$)	Mean TN ($mg\ m^{-3}$)	Mean TP ($mg\ m^{-3}$)	Estimated TLI	pH	Turbidity (NTU)
Mar 1988 - Feb 1989[a]	>2m in May 1988 >1m in Jan 1989	10	970	36			
a WRC water quality data (Located site 311_1)							

Surveys of submerged vegetation were carried out in 2004 and 2010. The results indicated that there had been a marked decline in Lake SPI scores between 1987- 2004, then a period of relative stability, followed by a slight decline between 2004 and 2010. The initial decline between 1987 and 2004 occurred as a result of *Egeria* re-invading the lake after a successful eradication in the early 1980's. Since it's reintroduction at some point after 1996, Egeria has again dominated the vegetation in the lake. The lake is currently classified as stable in regards to submerged vegetation (Edwards et al; 2010).

It is unknown whether the lake margin (c. 950m) is fenced, although the lake is not identified as a priority water body for stock exclusion in the WRP.

A DOC plant survey detected a very small remnant population of *Potamogeton ochreatus* on the north side of lake along with the other native submerged species *Potamogeton cheesemanii* and *Myriophyllum propinquum*. The native perennial herb *Glossostigma elatinoides* was recorded on the lake margins but is becoming sparse due to stock trampling. (Benham 2008). The introduced swamp lily *Ottelia ovalifolia* was recorded to be dense and problematic in the lake.

The lake once supported a valued trout fishery, but in the early 1970s the fishery declined as a result of deteriorating water quality, the introduction of rudd, and invasion by *Egeria densa*. Between 1976-1981, a biomanipulation restoration project was undertaken which involved the introduction of grasscarp to remove *Egeria* from the lake. Complete removal of all plants in this lake enabled the subsequent restructuring of the fish fauna. All fish species were removed with the application of rotenone which enabled the regeneration of submerged native plant communities in the absence of exotic fish and plants. The lake was restocked with trout and common bully after this re-establishment (Rowe and Champion; 1994). It is understood that *Egeria* was reintroduced to the lake sometime after 1996, and that grass carp were subsequently re-introduced to the lake by Fish & Game in 2008 to control *Egeria densa* (B. Wilson *pers. comm.*). It is unclear whether control has been achieved.

Egeria densa represents a key threat to the lake, and there is a risk that it may completely displace native charophytes and reach sufficient density to trigger a complete vegetation collapse. Stock access to the lake is affecting native plants at the lake margins, and may be contributing to the observed reduction of water quality. Fencing and planting of the riparian margin would protect some of the marginal plants and enhance the lake's overall condition, although weed control would probably be necessary to maintain marginal plant diversity.

Options for management and acquisition of information:

- assess the lake and its future management requirements in conjunction with other members of the MOA and landowners

- re-survey aquatic vegetation in the lake using Lake SPI
- survey other lake health indicators
- work with landowners in the lake catchment to encourage best management practices, including improved management of the lake margins (i.e. fencing & riparian planting).

5.2.3 Lake Puketi

Depth	7.0 m
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Stewardship land administered by Department of Conservation
Lake area	6.4 ha
Estimated catchment area	114.10 ha
Catchment land use	Drystock
Percent native vegetation cover in catchment	1.09%
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (14)	WRC zone (11)
Data deficient	Data deficient	Data deficient	Data deficient
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Puketi is one of a small group of coastal dune lakes that are located near the northern boundary of the Waikato region. The lake is located in close proximity to Lake Rotoiti.

The water quality of Lake Puketi was monitored at Coe's Road between November 1988 – January 1989. Waikato Regional Council also collected information on the lake as part of it Shallow Lake Health indicators programme during 2010/2011. Water quality data is presented in the table below.

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
Nov 1988 to Jan 1989[a]	>2m (May 1988) >1m (Jan 1989)	1	490	14			
2010/2011[b]	5.3	1	569	13	3.54	7.93	1.29
a WRC water quality data (Located site 312_1)							

b Waikato Regional Council Shallow Lake Health indicators programme (December/March/May)

The submerged vegetation of Lake Puketi was surveyed by NIWA in 1997 and 2004. The results indicate that the lake has been dominated by the invasive weed *Egeria densa* for at least 17 years. The most recent surveys indicate continued dominance by *E.densa*, although 3 (sparse) native charophyte species, 5 native turf plants and other native emergent species were recorded by NIWA in the 2004 survey (de Winton *pers. comm.*). *Chara fibrosa* var. *acanthopitys* was recorded by DOC during a recent visit (Benham 2008). NIWA observed that conditions during the last survey (in 2004) were likely to be stressful for submerged vegetation and that there was a risk of vegetation decline (Edwards *et al.* 2005). It is thought that the lake would have supported the type of charophyte-dominated vegetation that was described in neighbouring Lake Whatihua in 1950 (Edwards *et al.* 2005).

It is not known whether the lake margin (c.800m) is fenced to prevent stock access, but Lake Puketi is not identified as a priority water body for stock exclusion in the WRP. It is likely however, that the lake and its margins would likely benefit from fencing and weed control.

Grey willow are reported to occur in the lake margins, and do not appear to be under any management (Benham 2008).

There are various anecdotal reports of the fisheries values of the lake but no thorough surveys appear to have been carried out. Shortfinned eels, common bullies, rainbow trout and rudd are recorded to have existed in the lake in 1980 (NIWA Freshwater Biodata Information System (FBIS)).

Because there is insufficient information to rank that lake for its biodiversity values, it is a priority to visit this lake and assess its management requirements.

Options for management and acquisition of information:

- collect relevant information to enable Lake Puketi to be scored using the 'Methodology for ranking lake ecosystems for lake ecosystems for biodiversity management in the Waikato region' to enable its inclusion in the SNA Lake Ecosystems assessment
- assess the lake and its future management requirements in conjunction with members of the Waikato District Lakes & Wetlands MOA Group and landowners
- re-survey aquatic vegetation in the lake using Lake
- survey other lake health indicators
- work with landowners in the lake catchment to encourage best management practices, including improved management of lake margins (i.e. fencing & planting).

5.2.4 Lake Rotoiti (Little Lake)

Depth	7.0 m
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Private land
Lake area	1.2 ha
Estimated catchment area	41.93 ha
Catchment land use	Drystock
Percent native vegetation cover in catchment	0%
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (14)	WRC zone (29)
Data deficient	Data deficient	Data deficient	Data deficient
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Rotoiti is one of a small group of coastal dune lakes that are located near the northern boundary of the Waikato region (within Franklin district). The lake is located between Lakes Puketi and Whatihua.

Waikato Regional Council holds no water quality information for Lake Rotoiti

The submerged vegetation of Lake Rotoiti was surveyed by NIWA in 1987 and 2004. The results indicate that the lake has been dominated by the invasive weed *Egeria densa* for at least 17 years. NIWA predict that the lake is likely to have supported the type of charophyte dominated vegetation that was described in neighbouring Lake Whatihua in 1950 (Edwards *et al.* 2005).

It is not known whether the lake margin (c.1200m) is fenced to prevent stock access. While Lake Rotoiti is not identified as a priority water body for stock exclusion in the WRP, the lake and its margins would likely benefit from fencing and weed control.

Biological information is scarce for the lake, although NIWA's Freshwater Biodata Information System (FBIS) indicates that common bullies and rudd were caught from the lake in 1978.

Because there is insufficient information to rank that lake for its biodiversity values, it is a priority to visit this lake and assess its values and management requirements.

Options for management and acquisition of information:

- collect relevant information to enable Lake Rotoiti to be scored using the 'Methodology for ranking lake ecosystems for lake ecosystems for biodiversity management in the Waikato region' to enable its inclusion in the SNA lake ecosystems assessment
- assess the lake and its future management requirements in conjunction with members of the MOA and landowners
- re-survey aquatic vegetation in the lake using Lake SPI
- survey other lake health indicators
- work with landowners in the lake catchment to encourage best management practices, including improved management of lake margins (i.e. fencing & planting).

5.2.5 Lake Un-named 3

Depth	Unknown
TA	Waikato District Council
WRC zone	Lower Waikato
Land tenure	Private land
Lake area	2.3 ha
Estimated catchment area	Unknown
Catchment land use	Unknown
Percent native vegetation cover in catchment	0%
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (14)	WRC zone (14)
Data deficient	Data deficient	Data deficient	Data deficient
Figures in brackets indicate the total number of lakes included in assessment.			

Waikato Regional Council holds no ecological or water quality information for this dune lake, which is located to the south of Port Waikato near Ngatutura point.

It is not known whether the lake margin is fenced to prevent stock access, although the lake is not identified as a priority water body for stock exclusion in the WRP.

Because so little is known about this lake, it is a priority to visit and assess its condition and future management requirements.

Options for management and acquisition of information:

- seek approval from the landowners to visit this lake to assess its condition and future management requirements

- collect relevant information to enable this lake to be scored using the 'Methodology for ranking lake ecosystems for lake ecosystems for biodiversity management in the Waikato region' to enable its inclusion in the SNA Lake Ecosystems assessment
- assess the lake and its future management requirements in conjunction with members of the MOA and landowners
- work with landowners in the lake catchment to encourage best management practices.

5.2.6 Lake Waitamoumou

Depth	Unknown
TA	Waikato District Council
WRC zone	West Coast
Land tenure	Private
Lake area	2.4 ha
Estimated catchment area	Unknown
Catchment land use	Drystock
Percent native vegetation cover in catchment	Unknown
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✓ Stock exclusion is for Raglan with sites within about 2km upstream and 2km downstream of saltwater intrusion

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (33)	Lake type (14)	WRC zone (11)
Data deficient	Data deficient	Data deficient	Data deficient
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Waitamoumou is a small dune lake located on private land to the north of Raglan Harbour entrance.

Waikato Regional Council holds no ecological or water quality information about this coastal dune lake, which is situated to the north of the Raglan Harbour mouth.

Feedback from recent visitors to the lake suggest that the lake margin (c.900m) is not fenced to prevent stock access (D Klee *pers. comm.)* although the lake and its tributaries are identified as priority water bodies for stock exclusion in the WRP.

Because so little is known about this lake, it is a priority to visit and assess its values and future management requirements.

Options for management and acquisition of information:

- seek approval to visit Lake Waitamoumou, in order to assess its condition and future management requirements

- collect relevant information to enable Lake Waitamoumou to be scored using the 'Methodology for ranking lake ecosystems for lake ecosystems for biodiversity management in the Waikato region' to enable its inclusion in the SNA Lake Ecosystems assessment
- work with landowners in the lake catchment to encourage best management practices.

5.3 Waitomo district

5.3.1 Lake Harihari

Depth	8.5 m
TA	Waitomo District Council
WRC zone	West Coast
Land tenure	Private land - Lake bed administered by Taharoa Lakes Trust
Lake area	18.4 ha
Estimated catchment area	134 ha
Catchment land use	Drystock/Indigenous Vegetation
Percent native vegetation cover in catchment	3.79%
Applicable joint agency accord/MOA	✕
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (7)	Lake type (14)	WRC zone (11)
3=	1	1	1=
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Harihari is located on the West Coast of the Waikato region south of Taharoa township, and is currently accessed over private land.

Lake Harihari is notable for its high water quality and overall condition. Waikato Regional Council has studied the water quality of the lake between December 2006 - March 2012 as part of the Shallow Lake Health indicators programme.

These results indicate that the lake is mesotrophic-eutrophic although chlorophyll a measurements are within the range expected for oligotrophic lakes.

Investigations of zooplankton communities between 2006 and 2008 predicted the lake to be mildly eutrophic using the rotifer inferred trophic level index (Duggan 2007). Water quality data is presented in the tables below.

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
2006/2007[a]	4.71	2	285	15	3.5	7.7	1.1
2007/2008[b]	3.95	3.8	296	10.6	3.6	7.7	1.9
2008/2009[c]	4.10	4	361	11	3.71	7.63	2.2
2009/2010[c]	4.76	3	466	8	3.63	7.76	2.07.
2010/2011[c]	4.67	3	644	11	3.78	7.66	1.88
2011/2012[c]	5.17	2	268	8	3.26	7.5	1.26
2012/2013[c]	3.55	1.5	205	5.33		7.65	
May 2014[d]		<3	192	6		7.7	0.59

a Waikato Regional Council Shallow Lake Health indicators programme (pilot study) (December, January and March) (Neilson *et al.* 2007).

b Waikato Regional Council Shallow Lake Health indicators programme (December/March) (Neilson & Hamer 2008).

c Waikato Regional Council Shallow Lake Health indicators programme (December/March/May)

d Waikato Regional Council – Data deficient Lakes Survey 2014

Surveys of submerged vegetation in 2005, 2009 and 2014 indicate that the lake has retained a high and reasonably diverse level of submerged plant cover. Several invasive submerged plant species have been recorded including *Elodea canadensis* which forms beds in the mid-depth zone, co-existing with native pond weeds and milfoils (Burton et al. 2014). Overall the recorded Lake SPI indices for Lake Harihari were 50% (in 2005), 45% (in 2009), and 45% (in 2014) which ranked amongst the top 30% of lakes in the Waikato region, and exceeded Lake Taharoa. Evidence of black swan grazing was observed in 2014, which may contribute to the maintenance of native plant diversity and reduce the cover of *Elodea* (Burton et al. 2014).

In 2005 NIWA assessed the ecological condition of Lake Harihari, which was previously undescribed (de Winton et al. 2005). They concluded that the lake was in good condition for a lake of its size, depth and catchment type. However, they did observe a layer of dirty water at about 4m depth in the shallow north-western arm of the lake. Large numbers of kakahi (freshwater mussels) and freshwater sponges were commonly observed amongst the submerged plants, and native snails and the tiny pea mussel were also recorded. Common bully and lacustrine smelt were the only native fish that were observed during the submerged plant surveys, and also the only bycatch species in recent eel surveys (Chisnall & Ruru 2008).

Lake Harihari is valued as a customary eel fishery. The commercial fishery has been formally closed[76], although they have been heavily fished in the early 1990s and eel populations comprised predominantly smaller eels in 1994 (Chisnall & Ruru 2008). Concern about the low numbers of young eels present in the lake, and the apparent lack of recruitment led to the translocation of under-sized shortfinned eels from Lake Waahi in 1998, although recruitment concerns remain. Flow through the lake outlet is naturally intermittent, but the installation of a perched culvert in 2000 has further restricted elver recruitment to the lake (Chisnall & Ruru 2008). These factors have also impeded access for diadromous smelt, grey mullet, banded kokopu and inanga that have been recorded from the lake historically. As part of an experimental trial, Waikato Regional Council has installed polypropylene ropes on the culvert in an attempt to improve access into the lake for climbing diadromous fish species (particularly eels).

[76] when the North Island eel fishery entered the Quota Management System in 2004

A range of birds have been observed at the lake, including the threatened New Zealand dabchick. Other threatened wetland birds are known from neighbouring lakes and may utilise Lake Harihari as well.

Wetlands occur in the shallows at the margins of the lake. These areas are fairly free of weed species except for a few small infestations of grey willow and pampas. Both species are currently present in manageable levels and their eradication has been recommended as a matter of priority (Beard 2009).

NIWA reported the major threats to Lake Harihari as nutrient enrichment (reducing water clarity and promoting algal growth), invasive aquatic plant species, and pest fish introduction. They attributed the lake's water quality to a well developed fringe of reeds and an abundant population of mussels, but suggested that sensitive management of the farmland around the lake (including fencing of lake margins and inflow streams, preventing land erosion and minimising fertiliser use) would assist to protect the lake in the long term.

Lake Harihari is not identified as a priority stock exclusion waterbody in the WRP, but fencing and riparian management is required to safeguard the lake's water quality.

Waikato Regional Council has been working with one landowner to fence a protective margin of land along the southern, south-western and south-eastern boundaries of the lake. In January 2009 a fence was constructed that created a margin ranging between 20-80m wide (from the lake edge) around the southern edge of the lake. The fence also takes in large areas of wetland and coastal forest remnants and will provide an approximately 7.3 ha stock free margin on this property. Funding was also obtained through the Biodiversity Condition Fund to replant and manage the retired margins of the lake.

In their 2014 visit to Lake Harihari, NIWA observed substantial increases in the extent of emergent plants along shorelines that had been fenced since 2005 (Burton et al. 2014). They observed however, that those areas with stock access and open water may provide important habitat for shallow water plant species, including the regionally rare charophyte *Chara fibrosa.*

Waikato Regional Council has identified a need for ongoing lake health monitoring, and an assessment of risks to lake health in order to identify a programme of work to protect and enhance the condition of the lake. Waikato Regional Council is also continuing to work with Trustees of the two adjoining properties to address the remaining unfenced lake margins (approximately 60%) to the north and east of the lake, where cattle currently have access to the lake.

Preventing the introduction of pest fish and any further invasive plant species is also necessary to safeguard the water quality of the lake and its submerged native plant communities. This is likely to require lake access restrictions since boats and eel nets are the main vectors of introduced plants and pest fish. It is important to note that Lake Taharoa is the closest source of new weeds (particularly *Lagarosiphon major*) and that no pest fish have been reported historically from Lake Harihari.

Options for management and acquisition of information:

- continue to monitor lake health indicators
- work with landowners in the lake catchment to encourage best farm management practices to reduce farming impacts on the lake (i.e. development of property plans etc.)
- support where possible fencing projects to exclude stock from the entire lake margins and inflow streams (in conjunction with appropriate landowners)

- work with landowners to eradicate grey willow and pampas from wetland areas
- continued collaboration with lake owners (Taharoa Lakes Trustees), adjoining land owners and DOC with a view to establishing a formal management agreement for the Taharoa Lakes
- complete the fish passage (polypropylene ropes) experimental trial and provide recommendations for fish passage
- include Lake Harihari in the upcoming WRP reviews as a priority for stock exclusion and as a significant wetland
- work with the lake and land owners to reduce the risk of pest fish or new invasive plant species from entering Lake Harihari.

5.3.2 Lake Piopio

Depth	Unknown
TA	Waitomo District Council
WRC zone	West Coast
Land tenure	Private land administered by Taharoa Lakes Maori Trust
Lake area	0.2 ha
Estimated catchment area	28 ha
Catchment land use	Drystock
Percent native vegetation cover in catchment	16.47%
Applicable joint agency accord/MOA	✕
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District	Lake type (13)	WRC zone (11)
Data deficient	Data deficient	Data deficient	Data deficient
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Piopio is a very small coastal dune lake situated on the West Coast to the south-west of Kawhia harbour. The lake is owned and administered by the Taharoa Lakes Trustees.

Lake Piopio is connected via an outflowing stream to Lake Rototapu, which then discharges directly to the coast. Lakes Piopio and Rototapu are situated between the Taharoa lakes (Lakes Taharoa, Numiti and Rotoroa) to the north and Lake Harihari to the south. The lake appears to be deepest on the eastern margin.

Until recently, Waikato Regional Council held no information about the ecology or water quality of Lake Piopio. The lake was visited and surveyed in May 2014 by staff from WRC, DOC and NIWA to assess the submerged plants, water quality, marginal vegetation, fisheries and wildlife values of the lake. The results of this work are currently

in prep, but staff reported that Lake Piopio was the smallest and most degraded of the lakes that were visited (Bourke *et al.* in prep).

The following water quality measurements were obtained during this survey, which indicate that the lake has high levels of nutrient enrichment (being eutrophic).

	Mean SD (m)	**Mean Chl *a* (mg m^{-3})**	**Mean TN (mg m^{-3})**	**Mean TP (mg m^{-3})**	**Estimated TLI**	**pH**	**Turbidity (NTU)**
2014[a]	0.6	<3	192	6	4.43	7.7	11.5
a WRC data deficient surveys May 2014							

Fyke nets and minnow traps were set as part of the surveys, and a single migrant shortfinned eel was captured. At the time of survey, Lake Piopio was clearly isolated from Lake Rototapu, which has a substantial waterfall downstream, so fish access between Lake Piopio and the sea is clearly sporadic.

Despite its small size, Lake Piopio is likely to be used by at least some of the wide range of waterfowl species that utilise Lakes Taharoa and Harihari.

NIWA carried out a Lake SPI survey in Lake Piopio, and reported that there were no submerged plants in the lake. They indicated that they considered that the lake would have been unlikely to support them naturally so consider that Lake SPI was not an appropriate tool for use in this lake (M. de Winton *pers. comm.*).

Lake Piopio is not identified as a priority water body for stock exclusion in the WRP, and stock appear to have had regular access to the shallow, western shoreline where there is evidence of stock impact and disturbance on the lake margin.

Options for management and acquisition of information:

- work with the landowners to assess the future management priorities for Lake Piopio
- continued collaboration with lake owners (Taharoa Lakes Trustees), adjoining land owners and DOC with a view to establishing a formal management agreement for the Taharoa Lakes
- collect relevant information to enable Lake Piopio to be scored using the 'Methodology for ranking lake ecosystems for lake ecosystems for biodiversity management in the Waikato region' to enable its inclusion in the SNA Lake Ecosystems assessment
- include Lake Piopio in the upcoming WRP reviews as a priority for stock exclusion and as a significant wetland.

5.3.3 Lake Rototapu

Depth	9.8m
TA	Waitomo District Council
WRC zone	West Coast
Land tenure	Private land administered by Taharoa Lakes Trust
Lake area	2.0 ha
Estimated catchment area	28 ha
Catchment land use	Unknown
Percent native vegetation cover in catchment	16.47%
Applicable joint agency accord/MOA	✕
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District	Lake type (13)	WRC zone (11)
Data deficient	Data deficient	Data deficient	Data deficient
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Rototapu is a very small coastal dune lake situated on the West Coast, to the south-west of Kawhia harbour. Lake Rototapu receives water from Lake Piopio, and then discharges intermittently to the coast.

Until recently, Waikato Regional Council held no information about the ecology or water quality of Lake Rototapu. However, the lake was visited and surveyed in May 2014 by staff from WRC, DOC and NIWA to assess the submerged plants, water quality, marginal vegetation, fisheries and wildlife values of the lake. The following water quality measurements were obtained during this survey, and suggest that Lake Rototapu is mesotrophic (Bourke *et al.* in prep).

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
2014[a]	2.15	8	169	7	3.63	7.1	1.58
a WRC data deficient surveys May 2014							

Fyke nets and minnow traps were set as part of the surveys, and shortfin eels, common bullies and smelt were captured from the lake. At the time of the survey Lake Rototapu was disconnected from the sea. A waterfall also occurs downstream of Lake Rototapu, which further impedes fish access. The presence of smelt was unexpected, and it appears that a small non-migratory population has established in Lake Rototapu. Koura and healthy populations of freshwater mussels (kakahi) were also observed during the recent surveys.

Lake Rototapu is small but is proportionally deep (9.8m) with sandy, sloping margins. A floating sudd of emergent species (*Eleocharis sphacelata, Machaerina articulata, Typha orientalis, Phormium tenax*) extends over the steeper eastern margin of the lake to depths of 2m (Burton et al. 2014).

In the recent (2014) submerged plant survey, NIWA reported that Lake Rototapu had a moderate lake SPI index of 41%. Exotic weed species (*Elodea canadensis*) and water buttercup (*Ranunculus trichophyllus*) were reported from the lake, in conjunction with important native submerged plant communities - including pondweeds, shallower milfoils and sparse charophytes (Burton et al. 2014). These submerged plants grew mostly to a depth of 4-5m but sparse, individual pondweeds were also observed at 7m depth indicating that the lake may have had a deeper vegetation limit in the past and that plant growth may be limited by current water quality and light conditions.

Lake Rototapu is not listed as a priority waterbody for stock exclusion in the WRP. There is evidence of an historical fenceline around Lake Rototapu, but this fence is now in disrepair. As a result, stock currently has access to the wetland margins of Lake Rototapu.

Options for management and acquisition of information:

- work with the Taharoa Lakes Trust to determine its future management requirements
- collect relevant information to enable Lake Rototapu to be scored using the 'Methodology for ranking lake ecosystems for lake ecosystems for biodiversity management in the Waikato region' to enable its inclusion in the SNA Lake Ecosystems assessment
- continued collaboration with lake owners (Taharoa Lakes Trustees), adjoining land owners and DOC with a view to establishing a formal management agreement for the Taharoa Lakes
- include Lake Rototapu in the upcoming WRP reviews as a priority for stock exclusion and as a significant wetland.

5.3.4 The Taharoa lakes – Taharoa, Numiti and Rotoroa

The Taharoa lakes complex consists of 3 inter-connected coastal dune lakes – Lakes Taharoa, Numiti and Rotoroa. The lake beds are owned by the Taharoa Lakes Trustees.

TA	Waitomo District Council
WRC zone	West coast
Land tenure	Private land administered by Taharoa Lakes Trust
Estimated catchment area	4226 ha
Catchment land use	Indigenous Forest/Exotic Forest/Drystock/Mining
Percent native vegetation cover in catchment	31.56%
Lake level in WRP	✕
Applicable joint agency accord/MOA	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕

The lakes are mostly fed by surface flow and rainfall, while the lake outlet is via the Wainui Stream to the Tasman Sea. A 4.6m high dam (incorporating a fish pass) was constructed in the 1970s at the outlet of Lake Taharoa to abstract water for ironsand mining operations (Cromarty & Scott 1996).

The Taharoa Lakes support a valued customary eel fishery that was formally closed to commercial eel fishing in 2004 when the North Island eel fishery entered the Quota Management System. Historically, the lakes also supported a valued grey mullet fishery, although this fishery collapsed due to the construction of the dam, and the original design of the fish pass that was impassable to mullet (Strickland 1985).

The fish pass has been modified multiple times, which has improved catch rates to some extent, although catch rates are still considerably lower than those expected for similar-sized waters which indicate that recruitment is still somewhat limited. Slow eel growth rates in the Taharoa lakes have also been attributed to reduced availability of forage fish species (including inanga and smelt), and a high dependence on invertebrates. A high incidence of shagworm parasites were observed in eels from Lake Rotoroa in particular (Chisnall & Ruru 2008).

Reduced fish recruitment has been linked with reduced residual flows from the Taharoa catchment arising from water abstraction, and water retention during natural low flows (Chisnall & Bellingham 1998). The reduced amount of aquatic habitat available in the Wainui Stream[77] was also implicated in reducing the level of elver (and other diadromous species) recruitment (Chisnall & Bellingham 1998). Chisnall & Ruru (2008) suggest that remediation of the dam weir and appropriate riparian management in the lower Wainui Stream are necessary to prevent further decline of customary eel stocks.

In 2010, New Zealand Steel installed a new fish pass to improve fish passage. Monitoring data from July 2011-June 2012 indicated that shrimps, elvers, whitebait, eels, common bully, inanga, mullet and smelt had been trapped at the fish pass (NZS data supplied to WRC 2014).

5.3.4.1 Lake Taharoa

Depth	9.2 m
Lake area	216 ha
Identified as Priority 1 Stock Exclusion	✓ Lake Taharoa margins and one inflowing stream

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (7)	Lake type (14)	WRC zone (11)
5	2	2	3
Figures in brackets indicate the total number of lakes included in assessment.			

Visits to the lake in 1982 indicated that Lake Taharoa was oligotrophic. Waikato Regional Council has monitored the lake between 2006-2012 as part of its Shallow Lake Indicators programme. These data confirm that there has been a marked deterioration in water quality since the 1980s, with increasing nutrient and algal concentrations. The trophic status of the lake is now eutrophic.

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
1982[a]	1.7-3.2	6.4		9.2		9.17	
2006/2007[b]	1.26	25	637	42	5.1	7.8	8.7

[77] The length of the original stream by the control structure has been approximately halved and flows have been reduced substantially which has resulted in a significantly reduced amount of aquatic habitat for juvenile eels to hold while they undertake physiological adaptation to the freshwater environment, and is likely to have increased their predation risk.

2007/2008[c]	1.4	33	723	39	5.16	8.55	8.8
2008/2009[d]	2.4	3.8	417	20	4.01	7.6	3.2
2009/2010[d]	3.31	3	460	13	3.81	7.86	3.41
2010/2011[d]	2.48	8	734	22	4.46	7.76	4.93
2011/2012[d]	2.41	8	404	17	4.17	7.96	4.53

a Town (1982b) Averages of 4 sampling visits undertaken by WVA between January - March 1982

b WRC shallow lake health indicators programme (pilot study) (December, January and March) (Neilson *et al.* 2007).

c WRC shallow lake health indicators programme (December/March) (Neilson & Hamer 2008).

d WRC shallow lake health indicators programme (December/March/May)

Submerged vegetation surveys in 2001, 2007, 2010, and 2014 have concluded that the aquatic plant communities are generally vigorous and healthy, although dominated by the exotic species *Elodea canadensis* and *Lagarosiphon major. They report that native vegetation (pondweeds, milfoils and charophytes)* persist within the lake, but have been markedly affected by the presence of the exotic species.

In 2007, NIWA detected a substantial (by 1.5-2.5m) decrease in the depth extent of submerged plants (as compared to 2001) to a depth limit of 3.2m - which indicated a sustained reduction in the lake's water clarity. They also observed large numbers of unattached plants at this time which suggested that the plants had experienced a period of stress. These factors led to concerns about the stability of the lake and its vulnerability to further deterioration. Edwards et al. (2009) suggested that the vegetation and future water quality of Lake Taharoa could be affected by the combination of the lake's variable water clarity and exposure to wind. Subsequent surveys indicate that there has been a sustained improvement in long term water clarity that appears to have benefitted the deeper native charophyte meadows. In 2010 submerged aquatic plants had recovered to grow to a depth limit of 4.8m, which further increased to 5.7m in 2014 (Burton et al. 2014).

Lake Taharoa is identified as a Priority 1 Stock Exclusion Waterbody in the Waikato Regional Plan, but stock has been observed within the lake margin during recent visits and the lakes would benefit from fencing.

The extensive shallow margins of Lake Taharoa support a large wetland fringe with wetlands surrounding all major inflows. While the wetlands are dominated by native species, some weed species are also present. In 2001 grey willow was identified as a particular risk to Lake Taharoa because of its potential to occupy a significant area if uncontrolled. More recently, royal fern has also been identified in at least one marginal wetland at a relatively early stage of invasion. Management of these plants has been recommended as a matter of priority. WRC is currently working with Taharoa Lakes Trust to undertake a royal fern control programme in the Taharoa wetlands.

The exact cause(s) of Lake Taharoa's deterioration is unknown, although forest clearance, changing land use and erosion/sediment loss from the catchment are likely to be contributors. It is promising to note however, that the lake has retained several features that known to stabilise and protect the ecological integrity of freshwater lakes, including extensive native plant communities (and their seed banks), and large populations of filter-feeding mussels (kakahi).

Options for management and acquisition of information:

- undertake a full assessment of threats to Lake Taharoa's water quality
- survey lake health indicators regularly

- support and encourage community participation in lake and land care activities
- work with landowners in the lake catchment to encourage best management practices to reduce sediment and nutrient inputs to the Taharoa Lakes (including fencing & riparian management)
- collaborate with the Taharoa Lakes Trust, adjoining land owners and DOC to support the development and implementation of a management plan for the Taharoa Lakes
- ensure that ongoing monitoring of the new fish pass is undertaken to determine its effectiveness
- support and promote weed control initiatives to eradicate and/or control royal fern and grey willow from lake margins and adjoining wetlands
- Containment of *Lagarosiphon* which does not occur in other lakes in close proximity to Taharoa (eg Harihari).

5.3.4.2 Lake Rotoroa

Depth	Unknown
Lake area	22.4 ha
Identified as Priority 1 stock exclusion	✕ one inflowing stream (to the lake) is identified as a priority 1 stock exclusion waterbody only.

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District	Lake type (13)	WRC zone (11)
Data deficient	Data deficient	Data deficient	Data deficient
Figures in brackets indicate the total number of lakes included in assessment.			

Waikato Regional Council had no recent or historical water quality information for Lake Rotoroa until it was surveyed in May 2014 as part of a survey of data deficient lakes in the area. These surveys involved a 3 day visit from staff of WRC, DOC and NIWA to assess the submerged plants, water quality, marginal vegetation, fisheries and wildlife values of the lake. The results of this survey are in prep, but preliminary water quality information is summarised below. These results indicate that the lake is eutrophic-supertrophic with moderate to high levels of nutrient enrichment (Bourke *et. al.,* in prep).

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
2014[a]	1.48	21	743	43	5.05	7.7	7.4
a WRC data deficient surveys May 2014							

Town (1982b) reported on water quality results from 4 sampling visits the Taharoa lakes in 1982, but was unable to sample Lake Rotoroa at that time as the connection between Lakes Numiti and Rotoroa was blocked. However from anecdotal information, it seems likely that Lake Rotoroa was in a similar in condition to oligotrophic Lake Numiti at this time.

Chisnall & Ruru (2008) report that all of the Taharoa lakes had transparent waters devoid of filamentous algae or blue-green algal blooms during their eel surveys of 1993-94 and observe that the lakes have experienced substantial eutrophication since that time. High numbers of black swan and Paradise duck were also observed in Lake Rotoroa during these visits.

Fyke nets and minnow traps were set during recent surveys (May 2014) and shortfin and longfin eels, common bullies, smelt, and inanga were captured from the lake. A small school of adult grey mullet were also observed in a shallow embayment along the eastern shoreline that were feeding on diatoms along the top of the macrophyte beds (B. David, WRC, *pers. comm.*). A single koura was also caught in the traps.

A tributary of Lake Rotoroa is identified as a Priority 1 Stock Exclusion Waterbody in the Waikato Regional Plan, but this status does not apply to the lake itself. It appears that the lake margin is not fully fenced to exclude stock.

Options for management and acquisition of information:

- work with the Taharoa Lakes Trust to assess the condition of Lake Rotoroa and its future management requirements
- collect relevant information to enable Lake Rotoroa to be scored using the 'Methodology for ranking lake ecosystems for lake ecosystems for biodiversity management in the Waikato region' to enable its inclusion in the SNA Lake Ecosystems assessment
- work with landowners in the lake catchment to encourage best management practices to reduce sediment and nutrient inputs to the Taharoa Lakes (including fencing & riparian management)
- collaborate with the Taharoa Lakes Trust, adjoining land owners and DOC to support the development and implementation of a management plan for the Taharoa Lakes
- include Lake Rotoroa in the upcoming WRP reviews as a priority for stock exclusion and as a significant wetland.

5.3.4.3 Lake Numiti (Nukumiti)

Depth	9.1 m
Lake area	15.8 ha
Identified as Priority 1 stock exclusion	✕ only one inflowing stream is identified as a Priority 1 stock exclusion waterbody.

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District	Lake type (13)	WRC zone (11)
Data deficient	Data deficient	Data deficient	Data deficient
Figures in brackets indicate the total number of lakes included in assessment.			

Until recent (2014) surveys, Waikato Regional Council held little recent water quality information for Lake Numiti. Town (1982b) reported on water quality results from 4 sampling visits to Lake Numiti undertaken for the Waikato Valley Authority between 5 January - 10 March 1982. At that time, Lake Numiti was reported to be oligotrophic with a low nutrient enrichment status. On the basis of the most recent data it appears that the lake has undergone significant nutrient enrichment, as it is now super-trophic (Bourke et al. *in prep*).

Available water quality data is presented below:

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity NTU
1982[a]	2.5-2.8	19.42		12.6		9.4	
2014[b]	0.86	29	773	30	5.17	7.7	7.3

a Town (1982b) Averages of 4 sampling visits undertaken by WVA between January - March 1982

b WRC data deficient lakes survey May 2014

Chisnall & Ruru (2008) observed that the lake had experienced substantial eutrophication since these observations when they undertook eel surveys in 1993/94, 2000 and 2002. This is consistent with the deterioration in water quality that has occurred in Lake Taharoa.

During the 2014 surveys algal blooms were observed along parts of the lake shoreline (Burton et al. 2014).

In 1982 Lake Numiti was reported to have had a margin of *Ludwigia*, with surrounding vegetation comprised of small *Coprosma*, manuka, raupo (large areas), flax, sedges and lupin which provided habitat for threatened wetland birds, including bittern, North Island fernbird banded rail, and spotless crake. At this time, the main uses of the lake in 1982 were for eel fishing, duck shooting, and stock watering.

In 1983, divers recorded submerged vegetation growing to a depth of 6m at one of the recent Lake SPI survey sites. *Elodea* was the dominant submerged plant species at that time with charophyte meadows over a 5-6m depth range. In the most recent (2014) Lake SPI surveys, NIWA divers recorded plants at reduced vegetation depth limits of 2.8m. This reduction is likely to have occurred as a result of nutrient enrichment, reduced water clarity and algal blooms that affect the light climate for plant growth.

Fyke nets and minnow traps were set during recent surveys and shortfin and longfin eels, common bullies, smelt, and inanga were captured from the lake.

Lake Numiti is not identified as a Priority 1 Stock Exclusion Waterbody in the Waikato Regional Plan, and stock has been observed to access the lake and its margins. One of the lake inflows is identified as being a Priority 1 stock exclusion waterway in the WRP but it is not thought to be fenced.

Because there has been insufficient information to rank Lake Numiti for its current biodiversity values, it has been a priority to visit this lake and assess its condition and management requirements.

Options for management and acquisition of information:

- work with the Taharoa Lakes Trust to assess the condition of Lake Numiti and its future management requirements
- collect relevant information to enable Lake Numiti be scored using the 'Methodology for ranking lake ecosystems for lake ecosystems for biodiversity management in the Waikato region' to enable its inclusion in the SNA lake ecosystems assessment
- work with landowners in the lake catchment to encourage best management practices to reduce sediment and nutrient inputs to the Taharoa Lakes(including fencing & riparian management)
- collaborate with the Taharoa Lakes Trust, adjoining land owners and DOC to support the development and implementation of a management plan for the Taharoa Lakes
- include Lake Numiti in the upcoming WRP reviews as a priority for stock exclusion and as a significant wetland.

6 Waikato Karst lakes

Karst lakes are a rare lake type in New Zealand, and normally form (often temporarily) in enclosed depressions that are known as sinkholes, poljes and dolines (Viner 1987).

There are only two (known) shallow karst lakes that are greater than 1 ha in the Waikato region – Lakes Disappear and Koraha. Lake Disappear is located south of Raglan Harbour and is the largest known karst lake in New Zealand. The lake is ephemeral and periodically forms in the polje after wet weather when inflows are greater than the sinkhole can discharge. Lake Koraha is very small (0.8 ha) in comparison and appears to be in a highly natural condition.

Unfortunately, little is known about these lakes, and further information is required to assess their biodiversity values and overall condition. The following figures show their preliminary scores for different aspects of the lake prioritisation method that was used to rank karst and volcanic lakes in the Waikato region for their biodiversity values. Lake types are indicated by colour in the following way: volcanic, karst.

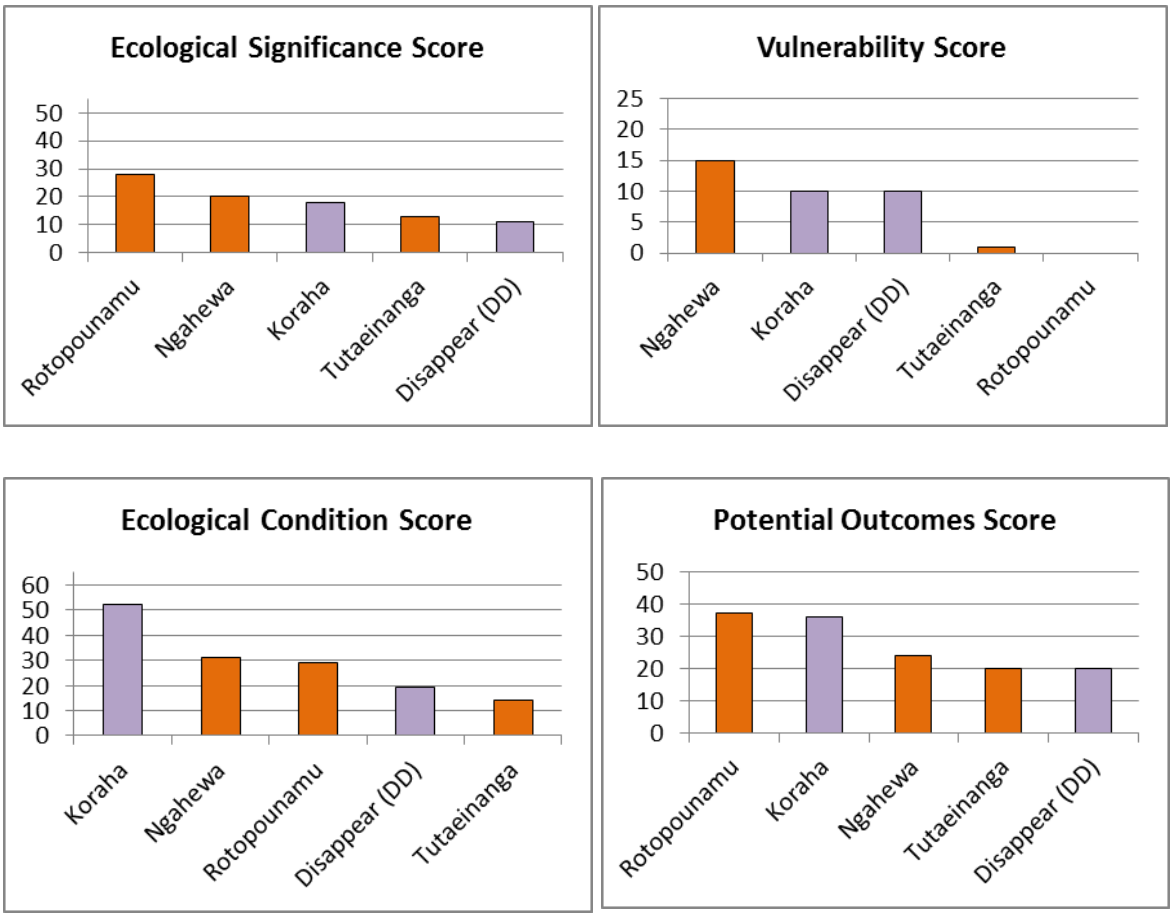


Figure 9 **Volcanic and Karst lake scores for different aspects of the lake prioritisation method used to rank lakes in the Waikato region for their biodiversity values** (Wildland Consultants 2011a).

6.1 Waikato District

6.1.1 Lake Disappear

Depth	Unknown
TA	Waikato District Council
WRC zone	West Coast
Land tenure	Private land
Lake area	Unknown
Estimated catchment area	599.5 ha
Catchment land use	Drystock
Percent native vegetation cover in catchment	13.47%
Applicable joint agency accord/MOA	Waikato Lakes & Freshwater Wetlands Memorandum of Agreement
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (4)	Lake type (2)	WRC zone (11)
Data deficient	Data deficient	Data deficient	Data deficient
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Disappear is an ephemeral lake that forms within a karst polje that is situated to the north east of Aotea Harbour. The polje is essentially a large karst depression with an alluvial floor that is drained by an underground stream. The lake fills after heavy rain when the flow of incoming water exceeds the rate of drainage. In drier weather the lake empties and disappears (Williams 2007, Kenny & Haywood 1996).

The polje is listed in the national geopreservation inventory as a landform of regional importance and at low risk of human induced damage (Worthy 1990, Kenny & Haywood 1996).

Waikato Regional Council holds no ecological or water quality information about Lake Disappear.

The site was assessed for pest control in 1999 and is reported at that time to have been dominated by adventive pasture species, with some indigenous wetland sedges, in the flat base of a broad gully. The report notes that the grassland is usually inundated with water in the winter, and indicates the site includes a remnant of secondary kahikatea forest on the adjoining hillslope (Wildland Consultants & Epro Ltd. 1999).

In 1999 the site (including the wetland) was unfenced and grazed (particularly in summer). Fencing is not required for ephemeral waterbodies under the WRP.

Because so little is known about Lake Disappear, and as ephemeral wetlands are rare terrestrial ecosystems (Williams *et al.* 2007), it is a priority to visit and assess the values and future management requirements of this site. Freshwater wetlands appear to be particularly scarce in the Kawhia ecological district.

Options for management and acquisition of information:

- seek approval to visit Lake Disappear, in order to assess its condition and future management requirements (in conjunction with landowners and other agencies)
- collect relevant information to enable Lake Disappear to be scored using the 'Methodology for ranking lake ecosystems for lake ecosystems for biodiversity management in the Waikato region' to enable its inclusion in the SNA lake ecosystems assessment
- work with landowners in the lake catchment to encourage best management practices
- investigate the biodiversity of the associated karst systems and the effect of land use and other on these values.

6.2 Otorohanga district

6.2.1 Lake Koraha

Depth	7.0 m
TA	Otorohanga District Council
WRC zone	West coast
Land tenure	Conservation area administered by Department of Conservation
Lake area	0.8 ha
Estimated catchment area	176.80 ha
Catchment land use	Indigenous forest
Percent native vegetation cover in catchment	67.56%
Applicable joint agency accord/MOA	✕
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (3)	Lake type (2)	WRC zone (11)
3=	1	1	1=
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Koraha is a small lake that is completely landlocked and drains via a small cave system at its western end. The lake is significant because it is one of very few lowland karst lake systems in New Zealand that are completely surrounded by native forest.

Waikato Regional Council staff visited the lake in February 2010 and took a single water sample – results are presented in table below. The lake water was observed to be

brown in colour and slightly acidic with a pH of 5.8. The lake bottom was observed to contain large amounts of organic matter, which is consistent with observations (of leaf litter, fines, branches and stumps in the water column) made in the 1980s when the lake was dived (P. de Lange *pers comm.*).

	Mean SD (m)	**Mean Chl *a* ($mg\ m^{-3}$)**	**Mean TN ($mg\ m^{-3}$)**	**Mean TP ($mg\ m^{-3}$)**	**Estimated TLI**
Feb 2010[a]			1200	67	
a WRC one off sample. pH					

The lake has not been sampled as part of Waikato Regional Council's Lake Health Indicators programme. However, a comprehensive plant species list was compiled by DOC staff who visited the lake in the mid-late 1980s (P. de Lange *pers. comm.*). During this time, the lake is reported to have been dominated by native submerged and emergent vegetation, and had no major naturalised aquatic macrophytes aside from scarce *Callitriche stagnalis*.

The lake is not identified as a priority water body for stock exclusion in the WRP however stock access is not perceived to be a risk to the lake because of its location within a Conservation Area.

There is no fisheries information for the lake, but the lake and its margins are known to support numerous green and golden bell frogs, and large numbers of dragon flies (K. Neilson, WRC *pers. comm*.).

Brown teal were reported from the lake in the 1980s and there are unconfirmed reports of other threatened native wetland birds using the lake margins, including North Island fernbird and spotless crake (P. de Lange *pers. comm.*). During the recent visit, several hoary headed grebe were seen on the lake.

In 1986 *Osmunda regalis* (royal fern) was first detected in the marginal wetland of the lake. This species has since expanded (particularly on the southern and eastern margins of the lake) and is now subject to a DOC weed eradication programme.

Because the lake and its catchment are highly natural, it may be important to include the lake in monitoring programmes as a high quality/reference site. Access limitations may be problematic though as 4WD access relies on approval access private property to reach the DOC reserve, with the last c.100m only accessible by foot only (through steep bush). This poses a challenge for future surveys and monitoring.

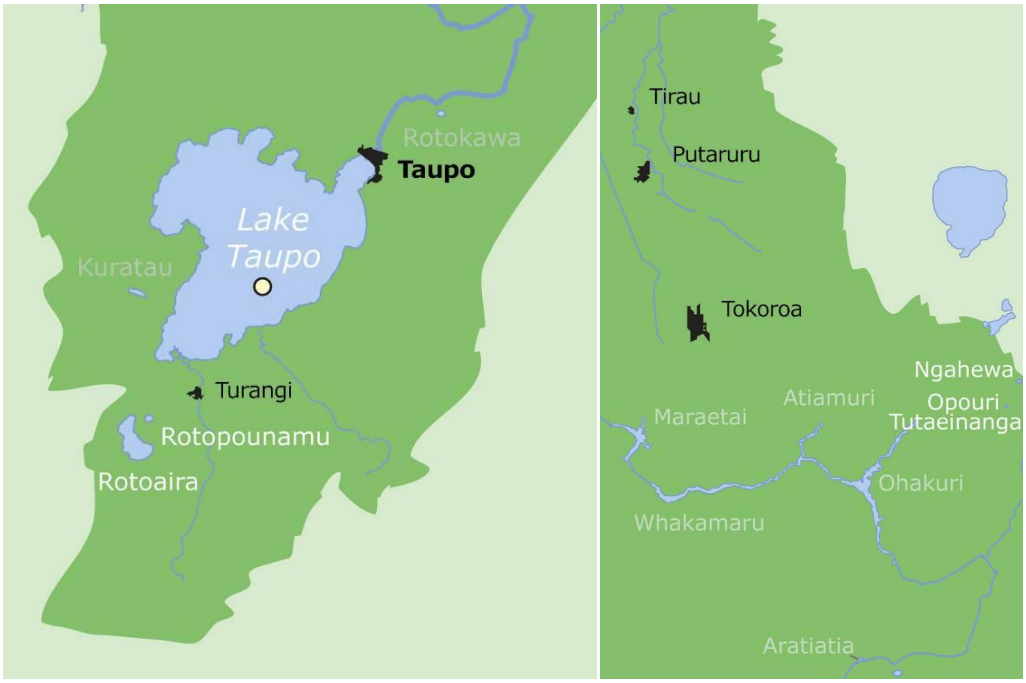
Options for management and acquisition of information:

- assess options for conducting lake health indicators assessment (incl. Lake SPI) at Lake Koraha;
- support DOC in its management of the lake and its margins (incl. weed control).

7 Waikato volcanic lakes

In New Zealand, volcanic lakes are largely confined to the Taupō Volcanic Zone and the area around Auckland. Whilst there are a large number of volcanic lakes within the Taupō volcanic zone, many fall within the Bay of Plenty region or are too deep to be classified as shallow lakes.

These lakes have formed in craters that have formed by explosive local eruptions (and associated faulting) within the last 10,000 years (Viner 1987). All three lakes are less than 10 ha in size with moderate to large catchments (500-750 ha).



Only 3 lakes (Lakes Rotopounamu, Ngahewa and Tutaeinanga) within the Waikato region are less than 10m deep. Each of these lakes are less than 10 ha in size with moderate to large catchments (500-750 ha). Land cover in these catchments ranges enormously from <1 % (Tutaeinanga) to 84% (Rotopounamu) cover of indigenous forest.

Lakes Rotopounamu, Ngahewa and Tutaeinanga were ranked by WRC for biodiversity management on the basis of available information (Wildland 2011), although recent information is scarce for Lake Rotopounamu. Figure 9 shows scores for different aspects of the lake prioritisation method for these volcanic and karst lakes.

Lakes Rotopounamu and Ngahewa have moderate scores for ecological significance and condition, unlike the highly modified Tutaeinanga that scores poorly for these criteria. Lake Tutaeinanga's poor condition is linked to the recent loss of submerged vegetation. Lake Ngahewa is far more vulnerable than the other two lakes whilst Lake Rotopounamu is largely protected by its location within a National Park.

7.1 Rotorua district

Lakes Ngāhewa, Tutaeinanga and Ngāpouri (Opouri) are found in the volcanic/geothermal area around Maungakakaramea (Rainbow Mountain) and Waiotapu.

The beds of these three lakes are under ownership by Te Arawa Lakes Trust and were part of the Te Arawa Lakes Settlement Act 2006. They are the only lakes of this

settlement which fall within the Waikato region. The remainder are within the area administered by the Bay of Plenty Regional Council

Only lakes Ngāhewa and Tutaeinanga are included in this plan as Lake Ngāpouri exceeds the classification depth for shallow lakes. Mention is made here of Lake Ngāpouri due to its hydrological links with Lake Tutaeinanga.

7.1.1 Lake Ngāhewa

Depth	5.5 m
TA	Rotorua District Council
WRC zone	Upper Waikato
Land tenure	Recreation reserve administered by Department of Conservation
Lake bed tenure	Te Arawa Lakes Trust
Lake area	8.4 ha
Estimated catchment area	746 ha
Catchment land use	Drystock/exotic forest
Percent native vegetation cover in catchment	5.22%
Applicable joint agency accord/MOA	✕
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (2)	Lake type (3)	WRC zone (4)
9=	1	2	1
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Ngāhewa is a volcanic lake located to the north of the Waiotapu thermal area. The lake bed is owned and administered by the Te Arawa Lakes Trust, while the surrounding 39.7 ha reserve (including wetlands) is administered by the Department of Conservation.

The main inflow into the lake is associated with a small spring feed stream system which meanders down the valley towards the lake crossing back and forth across State Highway 5. The stream and associated springs feeds large areas of flax swamp located at the head of the lake and in other small tributaries. The largest of these wetlands is within land administered by the Department of Conservation as a Recreation Reserve.

The water quality and limnology of Lake Ngāhewa has been studied at various times during the last 40-50 years. Fish (1968) described a dystrophic lake that was low in plankton when he studied it between 1961-1965. Forsyth & McColl (1975) studied the lake in 1973 and reported that the lake was better described as eutrophic (despite having dystrophic characteristics) due to it having high primary productivity, a diverse phytoplankton community, and high nitrogen (up to 36 mg m^{-3} NO_3-N) and phosphorus (42 mg m^{-3}) concentrations. Secchi depth (SD) transparencies of 1.5m and 3.3 m were

recorded during summer and winter, respectively. Water clarity was strongly correlated with algal production and humic inputs. Weak thermal stratification and oxygen depletion was also described in summer 1973 (Forsyth & McColl 1975) but appears to be infrequent. In 1986, Livingstone *et al.* reported the lake to be eutrophic, with a poor fishery and "fair" water quality.

Waikato Regional Council has studied the lake recently as part of a project investigating indicators of shallow lake health, which indicates that water quality has declined further from these original measurements.

The mean TLI of the three sampling occurrences is 5.8 which indicates a hypertrophic lake. Water quality data is summarised in the table below.

	Mean SD (m)	**Mean Chl *a* (mg m^{-3})**	**Mean TN (mg m^{-3})**	**Mean TP (mg m^{-3})**	**Estimated TLI**	**pH**	**Turbidity (NTU)**
2007/2008[a]	1.17	43	699	143	5.68	8.2	6.2
2008/2009[b]	1.45	47.13	1067	150	5.8	7.86	9.63
2009/2010[c]	1.01	60	839	240	6.01	7.67	5.46
a WRC shallow lake health indicators programme (pilot study) (December, January and March) (Neilson et al; 2007) b WRC indicators of shallow lake health project (December/March) (Neilson & Hammer; 2008) c WRC shallow lake health indicators programme (December/March/May)							

The submerged vegetation of Lake Ngāhewa has changed markedly since 1973 when the lake was reported to be free of exotic species and contained only *Potamogeton ochreatus* and *Nitella hookeri* (Forsyth & McColl 1975). By 1989 the native plants had been replaced by extensive beds of exotic macrophytes that subsequently collapsed. In 2004 the lake was essentially de-vegetated, but recent lake SPI surveys (in 2008) indicate that the vegetation has recovered to sufficient levels for survey (>10% cover). Both native and exotic plants were recorded in 2008, although *Lagarosiphon major* was the dominant species (Edwards *et. al.* 2009).

The lake supports a high diversity of zooplankton (at least 22 species) with a community composition that is typical of a lake with high concentrations of nutrients and algae. Using the rotifer inferred trophic state index, Lake Ngāhewa was predicted to be eutrophic (Duggan 2008).

Lake Ngāhewa is not identified as a priority water body for stock exclusion under the WRP. The Department of Conservation have established a 3 year fencing programme in conjunction with the landowners to replace/upgrade the boundary fences of the reserve so that they are stockproof. Waikato Regional Council has contributed to these fencing costs. Substantial planting has also been undertaken by the Department along the wetland edge which had been previously grazed by stock.

Because the lake occurs upstream of multiple hydro dams on the Waikato River and has strong geothermal influences downstream of the lake catchment (Waiotapu stream), fish passage to Lake Ngāhewa is poor. Common bullies, rainbow trout[78] and koura are the only species that have been caught in recent fisheries surveys of the lake (Boswell *et al.* 1985, Kelly 2010).

[78] stocked annually by Fish & Game

Waterbird surveys are conducted regularly, and recent DOC surveys in 2009 have confirmed the continued presence of a range of waterbird species of conservation significance - including NZ dabchick, North island fernbird, and spotless crake.

The emergent macrophyte and wetland vegetation associated with the lake is largely native and in good condition, with a relatively low abundance of exotic plants. The hydrological regime of the wetland has remained fairly intact with most areas inundated and maintaining water levels throughout the year. The wetland vegetation and wetland margins are being invaded by grey and crack willow, and Booth willow occurs along the stream to the west of the wetland (Kelly 2010). Willow management began in by the Department in 2010 with funding assistance from the Waikato Catchment Ecological Enhancement Trust. Two years of both ground and aerial control have occurred and it is expected the main control will be complete by 2013. Ongoing maintenance will be undertaken by the Department of Conservation. Extensive restoration planting is being undertaken along the wetland margins to reduce weed invasion now stock are removed.

Kelly (2010) has assessed the remaining threats to the lake as being invasion by other weed species (including submerged aquatics) and invasive fish. Identified threats to the wetland include terrestrial pests (possum, rats, stoat and wallaby) and willow and blackberry invasion.

Options for management and acquisition of information:

- support DOC in its management of the wetland surrounding Lake Ngāhewa
- continue to contribute to the fencing costs for replacement/upgrade of the DOC reserve boundary fence (2010 – 2013)
- monitor lake health indicators
- continued collaboration with the Te Arawa lakes Trust, and other management agencies (DOC, Fish & Game, and Rotorua District Council) on the management of Lakes Ngāhewa, Tutaeinanga and Ngāpouri.

7.1.2 Lake Tutaeinanga

Depth	11 m
TA	Rotorua District Council
WRC zone	Upper Waikato
Land tenure	Crown land administered by Eastern Fish and Game Council
Lake bed tenure	Te Arawa Lakes Trust
Lake area	3.1 ha
Estimated catchment area	501 ha
Catchment land use	Dairy
Percent native vegetation cover in catchment	0.80%
Applicable joint agency accord/MOA	✕
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (2)	Lake type (3)	WRC zone (4)
44	2	3	3
Figures in brackets indicate the total number of lakes included in assessment.			

The bed of Lake Tutaeinanga is owned and administered by the Te Arawa Lakes Trust. The lake margin (2.4 ha) is a Wildlife Management Reserve that is Crown Land administered by Fish & Game who have been appointed to control and manage the reserve until 2013. Much of the reserve is currently grazed. The lake has a narrow riparian margin that is dominated by exotic plants.

Lake Tutaeinanga flows via a drain to Lake Ngāpouri (Opouri). Lake Ngāpouri feds the Opouri stream which in turn flows into the Waiotapu stream.

Waikato Regional Council has assessed the lake recently as part of a project investigating indicators of shallow lake health. The mean TLI of the three sampling occurrences is 5.8 which indicates a hypertrophic lake. Water quality data is summarised in the table below.

	Mean SD (m)	Mean Chl *a* (mg m^{-3})	Mean TN (mg m^{-3})	Mean TP (mg m^{-3})	Estimated TLI	pH	Turbidity (NTU)
2007/2008[a]	1.20	69	1218	102	5.9	8.25	8.2
2008/2009[b]	2.18	62.47	2139	220	6.13	7.96	8.3
2009/2010[c]	1.82	24	1284	111	5.53	7.53	5.4

a WRC shallow lake health indicators programme (pilot study) (December, January and March) (Neilson et al; 2007)

b WRC indicators of shallow lake health project (December/March) (Neilson & Hammer; 2008)

c WRC shallow lake health indicators programme (December/March/May)

Lake SPI surveys have been conducted by NIWA in 2004 and 2008. In 2004, Edwards *et al.* (2005) reported that the lake had been partially invaded by *Egeria densa*, yet retained some areas of native vegetation. The 2008 lake SPI results indicate that the vegetation has since collapsed, and that the lake has become de-vegetated with occasional shoots of *Egeria densa* and *Potamogeton ochreatus* (Edwards *et. al.* 2008).

At least 13 species of zooplankton were recorded in water samples taken from Lake Tutaeinanga in December 2007 and March 08. Using the rotifer inferred trophic state index, Lake Tutaeinanga was predicted to be hypertrophic at this time (Duggan 2008).

Lake Tutaeinanga is not identified as a priority water body for stock exclusion under the WRP, although the reserve is fenced. However, the present fence is located very close to the lake and is not well aligned with the true reserve boundary. While it is stockproof, the current fence location limits the size of the riparian margin for the lake and therefore it's buffering capacity.

Waikato Regional Council holds no information about the biodiversity values of the lake. Because the lake occurs upstream of multiple hydro dams on the Waikato River and has strong geothermal influences downstream of the lake catchment (Waiotapu stream), fish passage to Lake Tutaeinanga is poor. Wildland (2009) reports that (lacustrine) smelt (*Retropinna retropinna*) have previously occurred in the lake, and that rainbow trout may be present. Fish and Game currently stock Lake Ngāpouri with Rainbow trout on a

regular basis. With the hydrological link to Tutaeinanga it is likely that rainbow trout (and other fish currently in Lake Ngāpouri) would also be present in Lake Tutaeinanga.

Fish & Game have expressed concern about the potential impact of subdivision around both Lakes Tutaeinanga and Ngāpouri. Both DOC and Waikato Regional Council would like to see the boundary fences adjusted (to reflect the true legal boundary) to extend the riparian margin. There appears to be some scope to enhance the condition of the lake by improving riparian management (including weed control and planting) and reducing nutrient inputs.

Options for management and acquisition of information:

- where possible provide support for DOC, Fish & Game and relevant landowners to realign the reserve boundary fence to improve riparian management
- conduct lake SPI survey
- monitor lake health indicators
- continued collaboration with the Te Arawa lakes Trust, and other management agencies (DOC, Fish & Game, and Rotorua District Council) on the management of Lakes Ngāhewa, Tutaeinanga and Ngāpouri.

7.2 Taupo district

7.2.1 Lake Rotopounamu

Depth	7.9 m
TA	Taupo District Council
WRC zone	Taupo
Land tenure	National park administered by Department of Conservation
Lake area	5.5 ha
Estimated catchment area	525 ha
Catchment land use	Indigenous forest
Percent native vegetation cover in catchment	84%
Applicable joint agency accord/MOA	✕
Lake level in WRP	✕
Identified as significant wetland (WRP Rule 3.7.7)	✕
Identified as Priority 1 stock exclusion	✕

Lake biodiversity ranking (Wildland Consultants 2011a)

Regional (71)	District (1)	Lake type (3)	WRC zone (1)
1	1	1	1
Figures in brackets indicate the total number of lakes included in assessment.			

Lake Rotopounamu is one of very few lakes in the region that are in close to pristine condition. The Lake is situated at high altitude (705m) within Tongariro National Park, and has its entire catchment in indigenous podocarp forest. The lake has a walking track around its entire margin and receives high numbers of visitors (Boswell *et al*. 1985). The

lake is administered by the Department of Conservation, and is identified as a priority freshwater site for conservation management. The lake was also selected as a Project Aqua site for the International Biological Programme that identified international waters for conservation (Luther & Rzoska 1971).

Lake Rotopounamu receives water from four small inflows but has no visible outlet. Michaelis (1982) reports that the lake has a mean depth of 4.65m and a volume of 4.14 x 10^6 m^3.

Waikato Regional Council holds no water quality information for Lake Rotopounamu but its water quality is expected to be high. Michaelis (1982) studied the lake in 1981 and attributed the comparatively low secchi depth measurement to the presence of fine detritus and silt in Lake Rotopounamu, as opposed to phytoplankton presence (Michaelis, 1982).

	Mean SD (m)	**Mean Chl *a* (mg m^{-3})**	**Mean TN (mg m^{-3})**	**Mean TP (mg m^{-3})**	**Estimated TLI**	**pH**
1981[a]	2.7		2.5 mg m^{-3} NO_3-N	6.0-27.6		7.1
a Michaelis, 1982						

The vegetation of Lake Rotopounamu has been studied on several occasions and is notable for its absence of tall growing native species, and the absence any exotic aquatic macrophytes. Michaelis (1983) surveyed the lake's vegetation in 1981 and reported that the lake had a poorly developed, discontinuous and narrow band of emergent macrophytes, dominated by *Baumea rubiginosa*, around its margin. Michaelis (1983) also described two distinct communities of submerged vegetation: (i) a low-growing inshore community dominated by *Myriophyllum pedunculatum* at 0.1 -2.5m depth*;* and (ii) a dense characean meadow containing *Nitella pseudoflabellata* and *N. leptostachys* var. *Ieonhardii* extending from 2.5 – 7.9m deep. An unusual liverwort complex was also described on the eastern beach that covered the sand to 0.6m depth and occurred again in deeper water.

The lake is known to have supported the extensive charophyte meadows described by Michaelis (1983) until at least 1990, after which time they collapsed. The most recent lake SPI survey was conducted in 2004 and the lake continued to score well (71%) despite the absence of charophytes. This is a result of the continued existence of native emergent and turf communities that extend to modest depths, and the continued absence of invasive submerged plants (Edwards *et al.* 2005). The cause of the charophyte collapse in Lake Rotopounamu is unknown, but plant remnants were found buried under a layer of silt during the 2004 survey. As a result, there is some speculation that the collapse may have resulted from geothermal activity, volcanic ash fall, or a landslide (Edwards *et al.* 2005).

Lake Rotopounamu is not identified as a priority waterbody for stock exclusion under the WRP. Because of its location, there is no risk of stock access to the lake, although pigs, possums and rats are being managed by DOC pest control programmes in the surrounding forest.

There is little documentation available on the aquatic fauna of Lake Rotopounamu, although Edwards et al. (2009) observes that the lake lacks some common components of submerged flora and invertebrates (e.g. mussels). Koaro (*Galaxias brevipinnis)*, common bullies (*Gobiomorphus cotidianus*) *and* koura/freshwater crayfish (*Paranephrops planifrons*) are reported from the lake, and common smelt (*Retropinna retropinna*) were introduced to the lake in the 1970s (McDowall 1990, Boswell *et al.*

1985, Michaelis 1982, Rowe 1993). Fisheries surveys in 1991 caught very few koaro, resulting in concerns that they had been displaced by smelt (Rowe 1993), although 2003 surveys by DOC indicate that smelt numbers have also declined (DOC 2004). No exotic freshwater fish species are known from Lake Rotopounamu.

The lake is known to support several bird species of conservation significance, including the North Island fernbird and the New Zealand dabchick.

Several exotic plant species have been recorded at Lake Rotopounamu. Edwards et al. (2005) report the presence of *Juncus bulbosus* and *Rananculus flammula* at the lake margin, but observe that these species are unlikely to be invasive. DOC has also identified heather (*Calluna vulgaris*) around the margins of the lake and consider it to be the most significant weed threat in the area (N Singers *pers. comm.*).

Because of its high visitation rate, and the presence of exotic submerged plant species in other lakes in the Taupo area, Lake Rotopounamu is vulnerable to invasion by exotic submerged macrophytes.

Options for management and acquisition of information:

- carry out a lake SPI survey
- where possible, support DOC in its management of Lake Rotopounamu to ensure that its current condition is maintained

8 References

Barea L 1996. Te Otamanui lagoon. DOC internal memo dated 11 July 1996.

Barnes GE 2001a. Aquatic and marginal vegetation of Lake Serpentine North. Environment Waikato Technical Report 2001/03. Hamilton, Waikato Regional Council (Environment Waikato).

Barnes GE 2001b. Ecological issues and restoration options for Te Otamanui lagoon. WRC Internal Memo dated 5 December 2001. Doc #719847.

Barnes GE, Martin A, Basheer G 2001. Opuatia Wetland restoration plan. Environment Waikato Internal Series 2001/14. Hamilton, Waikato Regional Council (Environment Waikato).

Barnes GE 2002a. Water quality trends in selected shallow lakes in the Waikato region, 1995 – 2001. Environment Waikato Technical Report 2002/11. Hamilton, Waikato Regional Council (Environment Waikato).

Barnes GE 2002b. Water quality trends in Lake Rotomanuka North – implications for restoration and management. Environment Waikato Technical Report 2002/03. Hamilton, Waikato Regional Council (Environment Waikato).

BCD Group 2014. Resource consent application to construct a new outlet weir and divert an existing inlet drain at Lake Ngaroto, Te Awamutu. Prepared for Waipa District Council.

Beard C 2009. Lake Harihari terrestrial vegetation and birdlife. Internal Waikato Regional Council document Doc #1460801.

Benham S 2008. DOC internal memo - Site Visit Report: Awhitu Peninsula threatened plant and kauri PTA survey. Dated 29 January 2008.

Bennett W 2014. Work programme for the restoration of wetland area associated with Lake Maratoto. Prepared for owners of Lochiel Properties.

Bodmin K Champion P., Matheson, F. 2008. Lake Mangahia management recommendations for lake level, marginal vegetation and nutrient removal. Environment Waikato Technical Report 2008/35. Hamilton, Waikato Regional Council (Environment Waikato)

Boswell J, Russ M, Simons M 1985. Waikato small lakes: resource statement. Waikato Valley Authority Technical Report 1985/7. Hamilton , Waikato Valley Authority.

Boubee JAT 1978a. Lake Maratoto: inventory and management draft. Prepared for Waipa County Council.

Boubee JAT 1978b. Lake Rotomanuka: inventory and management plan. Prepared for Waipa County Council.

Boubee JAT, Wilding T, Baker CF, Smith JP 2004. Lake Waikare fish pass monitoring 2003-04. NIWA Client Report prepared for Environment Waikato. HAM 2004-142. Doc #965970.

Bourke C, David B, Dean-Speirs T, Hamer M, Jepson A, Lake M, Scothern S, Whaley P, Emmitt T, Thurley T, Bridgman L, Wells R, DeWinton M, Taumoepeau A. 2014. Taharoa data deficient shallow lakes survey May 2014. Waikato Regional Council Technical Report TR2014/64. Hamilton, Waikato Regional Council.

Brown K, Campbell D, Brown E 2005. Eco-hydrological characterisation of Opuatia wetland and recommendations for future management. Environment Waikato Technical Report TR2005/17. Hamilton, Waikato Regional Council (Environment Waikato).

Burns NM, Rutherford JC, Clayton J 1999. A monitoring and classification system for New Zealand lakes and reservoirs. Journal of Lakes Research & Management 15(4): 255-271.

Burns NM, Bryers G, Bowman E 2000a. Protocol for monitoring trophic levels of New Zealand lakes and reservoirs. Ministry for the Environment, Wellington, New Zealand.

Burton T, de Winton M, Clayton J 2014. Assessment of lakes in the Waikato region Using Lake SPI. NIWA report for Waikato Regional Council. NIWA Client Report HAM 2014-062.

Buxton R, Russell G 1988. Lake Kimihia lake level setting: Staff report to Waikato Catchment Board Committee. Waikato Valley Authority Technical Report 1987/37. Hamilton, Waikato Valley Authority.

Champion PD, de Winton MD, de Lange PJ 1993. The vegetation of the lower Waikato lakes. volume 2: Vegetation of thirty-eight lakes in the Lower Waikato. NIWA-Ecosystems publication No.8. Hamilton, National Institute of Water and Atmospheric Research.

Champion PD, Wells RDS, de Winton MD 1996. The littoral vegetation of Lake Whangape: Historical changes, environmental influences and potential effects of water level manipulation. NIWA Consultancy report for the Department of Conservation (DOC 60207).

Champion PD, Beadel SM, Dugdale TM 2001a. Turf communities of Lake Whangape and some potential management techniques. Science for Conservation 186. Wellington, Department of Conservation.

Champion PD, Parkyn S, Chisnall BL 2001b. Rotokauri structure plan: Ecological asssessment. NIWA report for Beca, Carter, Hollings & Ferner. BCH 01201.

Chapman MA 1981. The summer limnology of Lake Waahi, New Zealand. Developments in Hydrobiology 2: 1-12.

Chapman MA, Boubee JAT 1977. Biological survey of the lakes of the Waipa County. Hamilton, University of Waikato, Department of Biological Sciences.

Chisnall BL, van Boven RJ, Hayes JW 1991. Fisheries surveys of Lakes Kimihia and Okowhao, and associated wetlands. New Zealand Freshwater Fisheries Miscellaneous Report No. 81. Rotorua, MAF Fisheries.

Chisnall BL, Bellingham M 1998. Review of the operation of the Taharoa fish-pass and associated fisheries issues. NIWA Client Report BHP 90202/1.

Chisnall BL, West DW, Lake MD 2007. Fish communities of Lake Whangape – February 2001 survey. DOC Research & Development Series 259. Wellington, Department of Conservation.

Chisnall BL, Ruru I 2008. Taharoa kakes customary eel fisheries. MFish Project EEL2006-06.

Clarkson B 2014. 2014. Lake Maratoto peatland: 20 years of vegetation change (1993-2013). Landcare Research report for Waikato Regional Council. Doc #3114850.

Clayton J, Edwards T 2006a. Aquatic plants as environmental indicators of ecological condition in New Zealand lakes. Hydrobiologia 570: 147–151.

Clayton J, Edwards T 2006b. Lake SPI: A method for monitoring ecological condition in New Zealand lakes: Technical report, version 2. Hamilton, National Institute of Water and Atmospheric Research.

Coal Corporation 1988. Huntly West underground coal mine water right applications and technical report. Coal Corporation of New Zealand Ltd.

Cromarty P, Scott D 1996. A directory of wetlands in New Zealand. Wellington, Department of Conservation.

Davenport M 1980. Setting of control levels for Lake Waikare: Comments relating to submissions from the Wildlife Service, Auckland Acclimatisation Society and Eel Fishery interests. WVA Internal Report No. 80/MWD/2. Hamilton, Waikato Valley Authority.

Davenport M 1981. Lake trophic status and water quality. Waikato Valley Authority Technical Publication No. 19. Hamilton, Waikato Valley Authority.

Dean H 2010. Lake Okoroire restoration and management plan. Report prepared for South Waikato District Council. Naturally Native NZ Plants Ltd.

Dean H 2011a. Lake Maratoto restoration plan. Consultancy repared for Judith Graham.

Dean H 2011b. Lake Rotokotuku wetland restoration plan. Consultancy report prepared for Waikato Regional Council. Doc #2177088.

Dean-Speirs T 2008. Assessment of the efficacy of a cube root powder operation at the Serpentine lakes. Consultancy report prepared for DOC.

de Lange P 2006. Indigenous vascular flora of Opuatia wetlands: A species checklist published by the NZ Plant Conservation network. www.nzpcn.org.nz/publications/Opuatia%20Vascular%20Plant%20List.pdf [accessed 19 June 2012]

de Winton MD, Clayton JS, Wells RDS, Tanner CC 1991. Review of Lake Rotoroa monitoring and management issues: 1987 to 1991. Hamilton, Ministry of Agriculture and Fisheries.

de Winton MD, Clayton JS 1996. The impact of invasive submerged weed species on seed banks in lake sediments. Aquatic Botany 53: 31-45.

de Winton MD 2002. Submerged seed banks in Lake Rotomanuka north. NIWA Client Report: EVW 02231. Waikato Regional Council report Doc #2201080.

de Winton M, Wells R, Matheson F 2005. An assessment of the ecological condition of Lake Harihari. NIWA Client report for the Lake Harihari Trustees.

de Winton M, Taumoepeau A 2005. Re-establishing submerged plants in Lake Rotomanuka North. NIWA Client Report: HAM2005-034.

de Winton M 2007. Management action plan for the Serpentine Lakes. Prepared by NIWA for the Department of Conservation.

de Winton M 2010. Serpentine Lakes: 2009-10 vegetation monitoring. NIWA Client Report HAM 2010-040. NIWA Project DOC 10206.

de Winton M, Safi K, Taumoepeau A, Burns N 2010. Lake Rotoroa monitoring: 2009/10. NIWA Client Report HAM2010-079 prepared for Hamilton City Council.

de Winton M 2011. Serpentine Lakes: 2010-2011 vegetation monitoring. Report prepared for the Department of Conservation. NIWA client report HAM2011-035.

Dell P, Holland L, Tutua-Nathan T 1988. Summary of the Lake Waahi catchment water and soil management plan. Waikato Catchment Board Technical Publication 88-56/1. Hamilton, Waikato Valley Authority.

Denyer K 2007. Opuatia wetland: Report on 5 years monitoring of wetland condition 2007. Environment Waikato report. EWDOCS# 1153803.

Department of Conservation 2004. Tongariro/Taupo Conservancy News. Rare Bits: The newsletter about threatened species work. No. 53. Published by the Department of Conservation, Wellington.

Diffuse Solutions Ltd 2008. Effects of urbanisation of the Rotokauri catchment on nutrient loads. Phase 1 report: Lake Rotokauri water quality objectives. Report prepared for Hamilton City Council.

Diffuse Solutions Ltd 2009. Effects of urbanisation of the Rotokauri catchment on nutrient loads. Phase 2 report: Water quality monitoring plan. Report prepared for Hamilton City Council.

Diffuse Solutions Ltd 2010. Effects of urbanisation of the Rotokauri satchment on nutrient loads. Phase 3 report: Rotokauri Stream monitoring and load calculations. Report prepared for Hamilton City Council.

Diffuse Solutions Ltd 2011. Effects of urbanisation of the Rotokauri satchment on nutrient loads: Phase 4 report: Predicted changes to nutrient loads after implementation of the Rotokauri Structure Plan (incorporating a summary of University of Waikato MSc study on the lake). Report prepared for Hamilton City Council.

Dugdale A, Reeves P 2002. Options for the management of Lake Roto Kaeo. NIWA Client Report HCC02228. Prepared for Hamilton City Council.

Duggan IC, Green JD, Shiel RJ 2001. Distribution of rotifers in North Island, New Zealand, and their potential use as bioindicators of lake trophic state. Hydrobiologia 446/447: 155-164.

Duggan IC 2007. An assessment of the water quality of ten Waikato lakes based on zooplankton community composition. Environment Waikato Technical Report 2007/34 Hamilton, Waikato Regional Council (Environment Waikato).

Duggan IC 2008. Zooplankton composition and a water quality assessment of seventeen Waikato lakes using rotifer community composition. Environment Waikato Technical Report 2008/26. Hamilton, Waikato Regional Council (Environment Waikato).

Duggan IC 2012a in press. Zooplankton composition and a trophic state assessment of fifteen Waikato lakes using rotifer assemblages: 2011-2012. Waikato Regional Council Technical Report 2013/05.

Duggan IC 2012b. Urban planning provides potential for lake restoration through catchment re-vegetation. Urban Forestry & Urban Greening **11**: 95-99.

Duggan IC 2014 in press. Zooplankton composition and trophic state assessment of 15 Waikato lakes using rotifer assemblages: 2012/13. Waikato University CBER Prepared for Waikato Regional Council.

Edgar N 1997. Lake ecosystem information strategy. Environment Waikato Technical Report 97/4. Hamilton, Waikato Regional Council (Environment Waikato).

Edwards T, Clayton J, de Winton M 2005. The condition of lakes in the Waikato region using lake SPI . Environment Waikato Technical Report 2006/13. Hamilton, Waikato Regional Council.

Edwards T, Clayton J, de Winton M 2008. The condition of 43 lakes in the Waikato region using lake SPI. Environment Waikato Technical Report 2008/36. Hamilton, Waikato Regional Council (Environment Waikato).

Edwards T, de Winton M, Clayton J 2009. Assessment of the ecological condition of lakes in the Waikato region using lake SPI: 2009. Environment Waikato Technical Report 2009/14. Hamilton, Waikato Regional Council (Environment Waikato).

Edwards T, de Winton M, Clayton J 2010. Assessment of the ecological condition of lakes in the Waikato region using Lake SPI: 2010. Environment Waikato Technical Report 2010/24. Hamilton, Waikato Regional Council (Environment Waikato).

Faithfull CL, Hamilton DP, Burger DF, Duggan I 2006. Waikato peat lakes sediment nutrient removal scoping exercise. Environment Waikato Technical Report 2006/15. Hamilton, Waikato Regional Council (Environment Waikato).

Fergie S 2003. Horsham Downs peat lakes: Resource inventory. Environment Waikato Internal Report Series IS03/04. Hamilton, Waikato Regional council (Environment Waikato).

Fish GR 1968. An examination of the trout population of five lakes near Rotorua, New Zealand. New Zealand Journal of Marine & Freshwater Research 2: 333-362.

Forsyth DJ, McColl RHS 1975. Limnology of Lake Ngahewa, North Island, New Zealand. New Zealand Journal of Marine & Freshwater Research 9(3): 311-332.

Garrick AS, Saunders AJ 1986. Flora and fauna in the Huntly West No. 1 coalfield area, a preliminary assessment: A Wildlife Service Environmental Investigations Unit report in collaboration with the Fisheries Research Division, Aquatic Plants section of the Ministry of Agriculture & Fisheries, and the Biological Sciences Department of the University of Waikato.

Golder Associates 2009. Huntly east mine: Ecology of Kimihia Stream and wetland. Report No. 087821431.

Greenwood J 1997. Lake Waikare: level effects study. Prepared for Environment Waikato and Rice Resources Ltd.

Greenwood J 2001. Lake Ngaroto restoration: A case study. Wellington, Ministry for the Environment.

Hamill KD 1995. Nutrient transformations in the lacustrine groundwater of a Waipa peat lake: Lake Serpentine. Unpublished MSc thesis. University of Waikato.

Hamill KD 1996a. Small lakes of the Waikato region: an information review and appraisal of water quality monitoring. Volume I – appraisal of Environment Waikato water quality monitoring. Prepared for Environment Waikato.

Hamill KD 1996b. Small lakes of the Waikato region: an information review and appraisal of water quality monitoring. Volume II – an information review for small lakes in the Waikato region. Prepared for Environment Waikato.

Hamill KD.1996c. Small lakes of the Waikato region: an information review and appraisal of water quality monitoring. Volume III – a bibliography for lakes in the Waikato region. Prepared for Environment Waikato.

Hamilton City Council 2002. Lake Rotokauri Park management plan. http://www.hamilton.co.nz/our-city/parks/parkmanagementplans/Documents/Lake%20Rotokauri%202002.pdf [accessed 22 November 2012]

Hamilton City Council 2009. Draft minor review of the operative Hamilton lake domain management plan, October 2009. Hamilton, Parks & Gardens Unit, Hamilton City Council.

Hamilton City Council. 2010. Waiwhakareke Natural Heritage Park: Draft management plan 2010. Hamilton, Parks & Gardens Unit, Hamilton City Council.

Hamilton City Council 2011. Waiwhakareke Natural Heritage Park: Operative management plan. Hamilton, Parks and Garden Unit, Hamilton City Council

Hamilton DP, Vant WN, Neilson K 2010. Lowland lakes. In: Waters of the Waikato. Part 4: Connected ecosystems. Hamilton, Waikato Regional Council (Environment Waikato) and the Centre for Biodiversity & Ecology Research (University of Waikato). 245-264.

Harrison Grierson Consultants 2011a. Surveys of Lakes A (Whakatangi), E (Tunawhakaheke) and Pikopiko. Prepared for Waikato Regional Council Doc #2255570.

Harrison Grierson Consultants 2011b. Survey of peat lakes: Maratoto and Ruatuna. Prepared for Waikato Regional Council Doc #2039760.

Hayes BE 2003. The law on public access along water margins. Wellington, Ministry of Agriculture & Forestry.

Hayes JW 1989. Comparison between a fine mesh trap net and five other fishing gears for sampling shallow-lake fish communities. New Zealand Journal of Marine & Freshwater Research. 23: 321-324.

Henriques PR 1979. A reconnaissance survey of Waitomo County freshwater swamplands. Waikato Valley Authority Un-numbered Technical Report. Hamilton, Waikato Valley Authority.

Hicks BJ, Reynolds G, Jamieson P, Laboyrie J 2001. Fish populations of Lake Ngaroto, Waikato, and fish passage at the outlet weir. Report prepared for Waipa District Council by University of Waikato. CBER Report 14.

Hicks BJ, Brijs J, Bell D 2009. Boat electrofishing survey of Lake Rotokaeo, Hamilton. CBER Contract Report 93. Hamilton, University of Waikato.

Hicks BJ, Brijs J 2009. Boat electrofishing survey of Lake Ngaroto. Report prepared for Waipa District Council by University of Waikato. CBER Report 111.

Hicks BJ, Baker C, Tana R, Powrie W, Bell D 2010. Boat electrofishing of the Waikato River upstream and downstream of the Huntly Power Station: spring 2010. CBER Contract Report No. 115. Hamilton, University of Waikato.

Holland L, Dell P, Tutua-Nathan T 1987. Lake Waahi catchment issues and options: A discussion document. Waikato Valley Authority Technical Report 1987/29. Hamilton, Waikato Valley Authority.

Hudson N, Quinn J, Rowe D, Tanner C, de Winton M 2008. Review of options for improving the condition of Lake Hakanoa. NIWA Client Report HAM 2008-067.

Jenkins B, Vant W 2006. Potential for reducing the nutrient loads from the catchments of shallow lakes in the Waikato region. Environment Waikato Technical Report 2006/54. Hamilton, Waikato Regional Council (Environment Waikato).

Kelly J 2010. Lake Ngahewa Recreation Reserve. Summary of current knowledge. DRAFT. Department of Conservation report. Rotorua Lakes Area Office.

Kenny JA, Haywood BW 1996. Inventory and maps of important geological sites and landforms in the Waikato region. Geological Society of New Zealand Miscellaneous Publication 85. Lower Hutt, Geological Society of New Zealand.

Kessels G 2007. Assessment of peat lake and wetland remnant. Prepared for Lochiel Properties Ltd.

Kingett PD 1984. An environmental history: Lake Waahi. Prepared by Kingett Associates for the Mines Division, Ministry of Energy.

Kirk T 1871. Notes on the botany of certain places in the Waikato district. Trans. N.Z. Inst. 3:142-147.

Lake Waikare Steering Group 2007. Lake Waikare management options. Environment Waikato Internal Report Series 2007/12. Hamilton, Waikato Regional Council (Environment Waikato).

Livingstone ME, Biggs BJ, Gifford JS 1986. Inventory of New Zealand lakes part 1: North Island. Water & Soil Miscellaneous Publication No. 80. Wellington, Ministry of Works & Development.

Luther H, Rzoska J 1971. Project Aqua: A source book of inland waters proposed for conservation. International Biological Programme Handbook. No. 21. Oxford, Blackwell Scientific Publications.

Macaskill B 1988. Huntly West No. 1 mine effluent ecotoxicity studies. Addendum entitled "Tissue Boron Levels in Egeria densa growing in Lake Waahi". Hamilton, DSIR Water Quality Centre.

Marra M, Trebilco U, Denyer K 2007. Progress toward achievement of Environment Waikato's Regional Policy Statement objectives: Biodiversity and natural heritage. Environment Waikato Policy Effectiveness Paper No. 1. Policy Series 2007/14. Hamilton, Waikato Regional Council (Environment Waikato).

McDonald A 2007. Lake Rotokauri weir – assessment of fish passage. Environment Waikato Internal Series 2008/3. Hamilton, Waikato Regional Council (Environment Waikato).

McDowall RM 1990. New Zealand freshwater fishes: A natural history and guide. Revised ed. Wellington, Heinemann Reed in association with MAF Publishing Group.

McLea MC 1986. Ohinewai regional resource study: Biology and water quality. Technical Publication No. 37. Hamilton East, Waikato Valley Authority.

Michaelis FB 1982. The lakes of Tongariro National Park. Mauri Ora 10: 49-65.

Michaelis FB 1983. Aquatic macrophytes of Lake Rotopounamu, a montane volcanic lake in New Zealand. New Zealand Journal of Botany 21: 33-38.

Ministry for the Environment 2001. Lake Ngaroto restoration: a case study. Wellington, Ministry for the Environment.

Moynihan KT 1986. Wildlife and sites of special wildlife interest in the western Waikato region. NZ Wildlife Service Fauna Survey Unit Report No. 41. Wellington, Department of Internal Affairs. NZ Wildlife Service.

Neilson K, Kelleher R, Barnes G, Speirs D, Kelly J 2004. Use of fine mesh monofilament gill nets for the removal of rudd from a small lake complex in Waikato, New Zealand. New Zealand Journal of Marine & Freshwater Research. 38: 525-539.

Neilson K, Collier K, Hamer M 2007. Assessment of biological indicators of lake health in Waikato shallow lakes: A pilot study. Environment Waikato Technical Report 2008/18. Hamilton East, Waikato Regional Council (Environment Waikato).

Neilson KA 2008. WRC Filenote: Site visit to Lake Milicich 12 May 2008. Waikato Regional Council Doc #1314910.

Neilson K, Kelleher R, Barnes G, Speirs D, Kelly J 2004. Use of fine-mesh monofilament gill nets for the removal of rudd (Scardinius erythropththalmus) from a small lake complex in Waikato, New Zealand. New Zealand Journal of Marine & Freshwater Research 38: 525-539.

Neilson K, Hamer M 2008. Sampling of lake health indicators 2007/08: Lakes Ngahewa and Tutaeinanga. Environment Waikato Internal Series 2008/17. Hamilton , Waikato Regional Council (Environment Waikato).

NIWA 2010. Waikato River independent scoping study. Prepared by NIWA for the Ministry of the Environment. NIWA Client Report HAM 2010-032. Project MFE 10201.

NIWA 2011 Assessment of sediment capping costs for Lake Rotoroa: A desktop study. NIWA Contract HAM 2011-119. Prepared for Hamilton City Council.

Northcote TG, Chapman MA 1999. Dietary alterations in resident and migratory New Zealand common smelt (Retropinna retropinna) in lower Waikato lakes after two decades of habitat change. New Zealand Journal of Marine & Freshwater Research 33: 425-436.

NZ Landcare Trust 2010. Lake Tunawhakaheke: Catchment action plan. Hamilton, NZ Landcare Trust.

NZ Landcare Trust 2011. Lake Ngaroto: background report. Compiled by Melinda Dresser and Nardene Berry for Ministry for the Environment.

Opus Consultants 2008. Waikato Lakes drain survey. Contract RCD 2007/08-63. GPS Survey of Drain Levels. A survey report prepared for Environment Waikato. (DM#167893).

Özkundakci D, Hamilton D 2012. Review of the Waikato Regional Council shallow lakes indicator project. Waikato Regional Council Technical Report 2012/20. Hamilton, Waikato Regional Council.

Page S 1988. Waipa lakes survey 1988. 70.271C Industry Report. Hamilton, University of Waikato.

Pridmore RD. 1992. Development of Horseshoe Lake and surrounding catchment. Consultancy Report No. 6051. Prepared by DSIR Water Quality Centre for Hamilton City Council.

Reeves P, Craggs R, Stephens S, de Winton M, Davies-Colley R 2002. Environmental changes at Lake Waikare, North Waikato. Wave climate, water quality and 'biology'. NIWA Client Report prepared for Environment Waikato. NIWA Client Report; EVW02235.

Rowe DK 1993. Disappearance of koaro, Galaxias Retropinna retropinna brevipinnis, from Lake Rotopounamu, New Zealand following the introduction of smelt. Environmental Biology of Fishes 36: 329-336.

Rowe DK, Champion PD 1994. Biomanipulation of plants and fish to restore Lake Parkinson: A Case study and its implications. In: Collier KJ ed. Restoration of aquatic habitats: Selected papers from the second day of the New Zealand Limnological Society 1993 Annual Conference. Wellington, Department of Conservation.

Rowe DK 2004. Lake restoration. In: Harding JS, Mosely MP, Pearson CP, Sorrell BK eds. Freshwaters of New Zealand. Christchurch, New Zealand Hydrological Society/New Zealand Limnological Society.

Ryan EF, Hamilton DP, Barnes GE 2003. Recent occurrence of Cylindrospermopsis raciborskii in Waikato lakes of New Zealand. New Zealand Journal of Marine and Freshwater Research 37: 829-836.

Sharma, A. 2011. A modelling approach to assist with managing water quality in a catchment subject to rapid urbanisation: Lake Rotokauri, Hamilton, New Zealand. Unpublished MSc Thesis. Waikato University, Hamilton, New Zealand

Singleton NP 1997. Lake Te Ko Utu water quality restoration and management proposal. Unpublished Waipa District Council Report.

Sledger RF 1981. Management decisions with regard to multiple use of resources. Paper A: Lake Waikare: A case study. In: Cramp C, Ridall G eds. The waters of the Waikato: Proceedings of a seminar held at the University of Waikato 20-22 August 1981. Volume II: 417-431.

Sondegaard M, Jeppesen E, Lauridsen TL, Skov C, Van Nes E, Roijackers R, Lammens E, Portielje R 2007. Lake restoration: successes, failures and long-term effects. Journal of Applied Ecology 44(6): 1095-1105.

Sorrell B, Unwin M 2007. Lake water quality in New Zealand: Status in 2006 and recent trends (1990–2006). Published report prepared for the Ministry for the Environment by NIWA.

Stephens S, Ovenden R 2003. Sediment resuspension and light attenuation in Lake Waikare: Phase 1 – lakebed sediments. NIWA client report HAM 2003-128. Hamilton, National Institute of Water and Atmospheric Research (NIWA).

Stockdale DF 1995. Sustainable peat lake management: The critical role of hydrological modelling: A Study of the Rotomanuka and Serpentine complexes, Ohaupo. Unpublished MSc thesis. University of Waikato, Hamilton, New Zealand.

Strickland RR 1985. Fisheries aspects of the Taharoa lakes and Wainui Stream. Fisheries Environmental Report No. 66. Rotorua, MAF Fisheries.

Sukias J, Wilding T, de Winton M, Tanner C 2006. Nutrient inputs to the Serpentine Lakes complex: Initial assessment and remediation tools. NIWA Client Report HAM 2006-046 prepared for the Department of Conservation. NIWA Project DOC 06210.

Sukias J, Ballantine D, Yates C 2009. Lake Serpentine infiltration filter monitoring. NIWA Client Report HAM 2009-092 prepared for DOC, Waipa DC, Environment Waikato and FRST. NIWA project DOC 09201. Hamilton, National Institute of Water and Atmospheric Research (NIWA).

Tanner CC, Wells RDS, Clayton JS 1987. Lake Rotoroa, Hamilton: Aquatic weed control, dissolved oxygen, water clarity and recommendations for future management. MAF Report prepared for Hamilton City Council. Hamilton, Ruakura Soil and Plant Research Station. Aquatic Impact Unit.

Tanner CC, Clayton JS 1990. Persistence of arsenic 24 years after sodium arsenite herbicide application to Lake Rotoroa, Hamilton, New Zealand. New Zealand Journal of Marine & Freshwater Research. 24: 173-179.

Tanner CC, Clayton JS, Coffey BT 1990. Submerged-vegetation changes in Lake Rotoroa (Hamilton, New Zealand) related to herbicide treatment and invasion by Egeria densa. New Zealand Journal of Marine & Freshwater Research. 24: 45-57.

Taylor A, Barnes G, Speirs D, Turner S, Vant B, Warnock T,Trebilco U 2004. Characteristics of high value water bodies in the Waikato region. Environment Waikato Internal Series 2004/04. Hamilton, Waikato Regional Council (Environment Waikato).

Teal PJ 2005. Report on water level restoration project 2005 at Penewaka Lagoon, Rangiriri. Fish & Game New Zealand, Auckland/Waikato region. Unpublished report.

Te Kowhai Community Group 2009. Support for a Community Walkway around the Te Otamanui Lagoon. A scoping study to Waikato District Council, October 2009.

Thompson K, Champion P 1993. Esplanade reserve recommendations for Lakes Serpentine, Mangahia, Rotomanuka, Ruatuna and Cameron (Waipa district). Conservation Advisory Science Notes No. 47. Wellington, Department of Conservation.

Thompson K, Greenwood JC 1997. Status of the Waipa peat lakes in 1997 with recommendations for restoration and sustainable management. A consultancy report prepared by the University of Waikato for Environment Waikato. Hamilton, University of Waikato.

Tonkin & Taylor 2005 Options for the management of Lake Te Ko Utu and surrounding park. Unpublished letter/report for Waipa District Council. (T&T job #60526.002).

Town JC 1980. Lake trophic status and water quality: 1980 survey. Waikato Valley Authority Technical Publication no. 16. Hamilton, Waikato Valley Authority.

Town JC 1982a. Application to discharge industrial waste from Waikato Carbonization Ltd to the Awaroa Stream. Internal report, Waikato Valley Authority. June 1982. File No. 20/W8.

Town JC 1982b. Lake trophic status and water quality: 1982 survey. Waikato Valley Authority Technical Report No. 22. Hamilton, Waikato Valley Authority.

Vant WN 1987. Lake Whangape: Muddy waters and macrophytes. Soil & Water Vol 23: 20-24.

Verburg P, Hamill K, Unwin M, Abell J 2010. Lake water quality in New Zealand 2010: Status and trends. NIWA client report HAM2010-107. Prepared for Ministry for the Environment. Hamilton, National Institute of Water and Atmospheric Research (NIWA).

Viner AB 1987. Inland waters of New Zealand. DSIR Bulletin 241. Wellington, DSIR.

Waikato District Council 2011. Lake Kainui recreation and esplanade reserves: Draft management plan. Ngaruawahia, Waikato District Council.

Waikato District Council 2012. Huntly domain and Lake Hakanoa reserve management plan. Prepared by Boffa Miskell for Waikato District Council.

Waikato Valley Authority 1980. Lake Rotokauri: A management guideline. WVA Technical Publication No. 15. Hamilton, Waikato Valley Authority.

Waikato Valley Authority 1987. Lake Waahi catchment resource statement. WVA Technical Publication No. 50. Hamilton, Waikato Valley Authority.

Waipa District Council 2007. A plan for the management of peat lakes and associated reserves administered by the Waipa District Council. Te Awamutu, Waipa District Council.

Waipa District Council 2009. Lake Ngaroto recreation reserve: Reserve management plan. Te Awamutu, Waipa District Council.

Waikato Regional Council 2012. Nutrient enrichment of shallow lakes: State of the Environment Indicator: http://www.waikatoregion.govt.nz/Environment/Environmental-information/Environmental-indicators/Freshwater/Lakes [accessed 21 November 2012]

Ward FJ, Northcote TG, Chapman MA 1987. The effects of recent environmental changes in Lake Waahi on two forms of the common smelt, Retropinna retropinna, and other biota. Water, Air & Soil Pollution 32: 427-507.

Warr S 1988. Review of the current status of Lake Rotokauri: Summary report prepared for Waikato District Council and Hamilton City Council.

Wells RDS 1976. The utilisation of the lower Waikato Basin by the Grey Mullet Mugil cephalus, Linneaus. Unpublished MSc thesis, University of Waikato, Hamilton, New Zealand.

Wells RDS, Vant WN, Clayton JS 1988. Inorganic suspensoids and submerged macrophytes in Lake Whangape, New Zealand. Verhandlungen des Internationalen Verein Limnologie 23: 1969-1972.

West DW, Roxburgh AJ, Chisnall BL 2000. Fish communities of Lake Whangape, Waikato: April 2000 survey. Conservation Advisory Science Notes 322. Wellington, Department of Conservation.

Wilcock RJ, Monaghan RM, Quinn JM, Srinivasan MS, Houlbrooke DJ, Duncan MJ, Wright-Stow A, Scarsbrook MR 2013. Trends in water quality of five dairy farming streams in response to adoption of best practice and benefits of long-term monitoring at the catchment scale. Marine & Freshwater Research. 64: 401-412.

Wildland Consultants, Epro Ltd 1999. Key ecological sites for pest control in private tenure in Waikato region – Waikato district and part Franklin district. Contract report No. 236. Prepared for Environment Waikato. Hamilton. Waikato Regional Council (Environment Waikato).

Wildland Consultants Ltd 2008. A preliminary assessment of the effects of two management proposals on marginal plant communities and wetlands birds at Lake Ngaroto. Prepared by Wildland Consultants for Waipa District Council. Rotorua, Wildland Consultants Ltd.

Wildland Consultants Ltd 2009. Scoring and ranking of lake ecosystems in the Waikato region for biodiversity management: Final report. Contract Report No. 2091a. Prepared for Environment Waikato. Rotorua, Wildland Consultants Ltd.

Wildland Consultants Ltd 2010a. Assessment of effects of two options for managing water levels at Lake Ngaroto. Prepared by Wildland Consultants for Waipa District Council. Rotorua, Wildland Consultants Ltd.

Wildland Consultants Ltd 2010b. Enhancement of eel habitat at Lake Okowhao, and eel access to and from the Waikato River. Contract Report No. 2218. Prepared for Eel Habitat Enhancement Working Group, Genesis Energy. Rotorua, Wildland Consultants Ltd.

Wildland Consultants Ltd 2011a. Significant natural areas of the Waikato region: Lake ecosystems. Waikato Regional Council Technical Report 2011/5. Hamilton, Waikato Regional Council.

Wildland Consultants Ltd 2011b. Vegetation assessment and restoration potential of Lake Whangape wildlife management reserve. Prepared by Wildland Consultants for the Department of Conservation, Hamilton. Rotorua, Wildland Consultants Ltd.

Wildland Consultants Ltd 2011c. Current extent and potential distribution of yellow flag iris in parts of the Lower Waikato River Catchment. Prepared by Wildland Consultants Ltd for the Department of Conservation and Waikato Regional Council, Hamilton. Rotorua, Wildland Consultants Ltd.

Wildland Consultants Ltd 2011d. Opuatia peat bog management plan. Waikato Regional Council Technical Report 2011/10. Hamilton, Waikato Regional Council.

Wildland Consultants Ltd 2011e. Vegetation assessment of Lake Rotongaro Wildlife Management Reserve. Prepared by Wildland Consultants for the Department of Conservation, Hamilton. Contract Report no. 2712. Rotorua, Wildland Consultants Ltd.

Wildland Consultants Ltd 2012a. Inter-Agency action plan for Lake Areare. Report prepared by Wildland Consultants for Parties to the Waikato District Lake and Wetlands Memorandum of Agreement. Contract Report no. 2995. Rotorua, Wildland Consultants Ltd.

Wildland Consultants Ltd 2012b. Stocktake of current and future management actions and opportunities for collaborative action at Waikato District Lakes and Wetlands. Report prepared by Wildland Consultants for parties to the Waikato District Lake and Wetlands Memorandum of Agreement. Contract Report no. 2766. Rotorua, Wildland Consultants Ltd.

Wildland Consultants Ltd 2012c. Vegetation assessment of kahikatea forest remnants and the southern-eastern margin of the Awaroa Swamp Wildlife Management Reserve, Lake Whangape. Prepared by Wildland Consultants for teh Department of Conservation, Hamilton. Contract Report no. 2835. 27p.. Rotorua, Wildland Consultants Ltd.

Wildland Consultants Ltd 2013. Ecological impacts of the flood control scheme on Lake Waikare and the Whangamarino Wetland, and potential mitigation options. Draft. Prepared by Wildland Consultants for the Department of Conservation and Waikato Regional Council, Hamilton. Contract Report no. 2766. Rotorua, Wildland Consultants Ltd.

Williams P, Wiser S, Clarkson B, Stanley M 2007. New Zealand's historically rare terrestrial ecosystems set in a physical and physiognomic framework. New Zealand Journal of Ecology 31(2): 119-128.

Williams P 2007. Limestone Country, Te Ara – the Encyclopedia of New Zealand, updated 21 September 2007. http://www.TeAra.govt.nz/TheBush/Landscapes/LimestoneCountry/en [accessed 22 November 2012]

Worthy T 1990. Inventory of New Zealand caves and karst of international, national and regional importance. 2nd ed. Geological Society of New Zealand Miscellaneous Publication No. 47. Lower Hutt, Geological Society of New Zealand.