Review of the Lake Ōmāpere Restoration and Management Project

Report prepared for Northland Regional Council

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Executive Summary

- Lake Ōmāpere, located near Kaikohe, is Northland's largest lake at 1160 ha. The lake has one outflow, the Utakura River, which flows into the Hokianga Harbour and a reasonably small catchment (2110 ha), which is a mix of dairying, drystock farming and lifestyle properties. The lake is shallow with an average water depth of 2 m.
- Lake Ōmāpere was vested to the Lake Ōmāpere Trust in 1954 by the Maori Land Court. The lake has considerable potential as an environmental, economic and recreational resource. Lake Ōmāpere is an important taonga to Ngapuhi. The lake and its catchment are also important ecologically.
- The lake has been impacted by land use change and other human actions, including pastoral farming and drainage of wetlands, causing a decline in water quality. The lake was further degraded by the introduction of oxygen weed (*Egeriadensa*) in the 1970s, which thrived in the enriched waters quickly covering the entire lake. The weed collapsed in 1985 causing severe blue-green algal blooms. Silver carp introduced in 1986 were unsuccessful in controlling the algal blooms. The oxygen weed increased again covering the entire lake by 1999. The weed collapsed again in 2001/2002 and the algal blooms returned. Grass carp were released into the lake to control the oxygen weed in 2000 and 2002. The weed was completely eradicated by 2003.
- The poor water quality has made the Lake and Utakura River unsuitable as water supplies, affected food sources from the Lake, River and upper Hokianga Harbour and led to restrictions on recreational uses, such as swimming and wakaama.
- The Lake Ōmāpere Restoration and Management Project was a joint initiative between NRC and the LOT funded by the Ministry for the Environment's Sustainable Management Fund that started in December 2003 and ended in June 2006.
- The overall aims of the project wereto develop and implement a voluntary lake management strategy that will work towards improving the health of the lake and help establish the Lake Ōmāpere Trustees in their role as Kaitiakitanga. The project had six main outcomes, including the development of a Lake Ōmāpere Management Strategy, weed management programme and integrated catchment management programme, enhancement of indigenous biodiversity, water quality monitoring and reporting and to assist the Trustees in their role as Kaitiaki for the Lake.
- The Lake Ōmāpere Project Management Group was established with representatives fromNRC, LOT, TRAION and FNDC.Detailed work was carried out by LOT, NRC, FNDC, DOC, landowners and many other key stakeholders throughout the project to complete the tasks required by the SMF contract. This included several Hui and public meetings, farm mapping and development of environmental farm plans, riparian fencing and planting, surveys of aquatic plants, mussels, fish and terrestrial plants, water quality monitoring and the development of the strategy with kaitakitanga as the overarching framework. Substantial work has continued since the project finished, including riparian fencing and planting, finalising of farm plans, mussel, plant and fish surveys and water quality monitoring.
- The *Restoration and Management Strategy for Lake Ōmāpere* was signed and launched on 29 September 2006.Farm mapping has been carried out for 14 landowners (about 72% of the catchment) and farm plans were finalised for eight landowners and drafted for a further two (about 45% of the catchment in total). By 2011, over 54 kilometres of

fencing in total has been carried out to exclude stock from the lake, streams, drains and wetland areas. In total 17.5 kilometres of fencing has been erected around the lake margin to exclude stock from the lake, lakeside bush and lakeside wetlands. Approximately 84% of the lake margin is now fenced with only two landowners that have not fenced their lake margin, totalling 2.6 km.Since 2005 there has been at least 11 planting days held, with over 250 volunteers assisting and over 10,000 plants being put in the ground.

- From July 2003 to June 2010, over $630,000 has been used to undertake the project tasks and ongoing work since the project finished. Additionally, over 10,000 inkind hours have been contributed. This includes contributions from NRC, LOT, FNDC, DOC, TRAION, NgaWhenuaRahui, MFE, landowners and other key stakeholders and organisations.
- The project was successful because:
    - the majority of SMF project tasks were completed on time within budget
    - the project outcomes/outputs have provided tools that can assist the trustees in their role as kaitiaki
    - people who have provided feedback on the project have responded that it was successful
    - most farmers in the catchment that weren't already doing BMP, have improved their farming practices
    - a substantial amount of riparian management has been undertaken
    - riparian management has led to enhanced indigenous biodiversity in the catchment.
- The success of the project can mainly be attributed to its' voluntary nature, the input and support from the community, the availability of funding and the commitment and time of a few people in key organisations. This highlights the value of having sufficient staff in appropriate organisations to coordinate or assist with regionally significant restoration projects and the need for on-going support and funding to carry out the work.
- There would not have been as much achieved in the same timeframe if an entirely regulatory approach was used instead of the voluntary approach, however, there is evidence that suggests that some regulatory mechanisms are required to support a voluntary approach. It is unclear whether a regulatory approach would have had a lower or higher capital cost but it is likely to have required less inkind contributionsthan the voluntary process followed.
- Lake water quality has improved since 2007 but this is most likely as a result of a natural phenomenon in the lake with the state switching between algal dominated and macrophyte dominated, rather than due to the project and restoration efforts. The available data suggests lake sediments still contain high nutrient levels, which provide an internal nutrient source through the wind resuspending sediment into the water column. The data also suggests that external inputs into the lake have not improved. Nutrient levels in catchment streams and drains are still high. Mussel numbers are stable in the lake and as they can filter algae from the water column, they are likely to be one of the main reasons for the lake improving.

- Research shows that it can take many years, even decades to see improvements in water quality as a result of restoration efforts. In many lakes, while changes in the catchment will work towards reducing external inputs to the lake, sustained improvement will not be achieved until the nutrients from the sediment have been removed from the lake system.
- This report has also highlighted that the effectiveness of riparian management varies depending on what objectives are trying to be achieved and in most cases should be used in conjunction with other management practices to be successful eg, wetlands to remove nitrogen and encouraging landowners to use BMP.This also highlights the importance of setting realistic objectives, clearly communicating to key stakeholders on how long it could take to achieve these objectives and reporting on progress.
- Although there is no evidence that can link improvements in lake water quality to the project, the strategies and programmes developed as part of the project are critical to ensuring the lake remains stable in this improved water quality state or improves further. For example, the weed management programme is vital to ensuring that oxygen weed and other invasive aquatic weeds are kept out of the lake and its catchment. The aim with any restoration project should be to achieve sustained improvement.
- Several recommendations for future monitoring and management are made. The few considered to be of highest priority are: resuming sampling at 75% depth, completing the fencing of the lake margin,regular weed surveillance in the lake and catchment waterways, public awareness on the spread of aquatic weeds and maintenance of the rock wall at the outlet.

Contents

Introduction

This report summarises and reviews the Lake Ōmāpere Restoration and Management Project. The report covers project objectives, what approach was taken, what was achieved and what it cost. The report briefly looks at what has been done since the project ended. Then detailed information on the current state of the lake and trends over time are presented including water quality, ecological condition and biodiversity. Then using available data and information this report looks at whether the project was successful in terms of:

- the project outcomes
- restoring Lake Ōmāpere, including changes in water quality and ecological condition
- assisting the trustees in establishing their role as kaitakitanga.

Finally, there is some brief discussion of the findings, including some lessons learnt and recommendations for future monitoring and management.

Incorporated into this report is feedback sought from the Lake Ōmāpere Trust (LOT), Northland Regional Council (NRC) and key stakeholders that were involved in the project and/or farm plan process. This includes three Lake Omapere Trustees, five NRC staff, one FNDC staff, an ex-TRAION staff, an ex-DOC staff and eight landowners.

Background

The Lake

Lake Ōmāpere, located nearKaikohe, is Northland's largest lake at 1160 ha. The lake is believed to have formed approximately 80,000 years ago through blockage (not likely to be by a lava flow) of the drainage from a swampy alluvial floodplain (Newnham et al. 2004). Evidence suggests there were periods where the lake became dry or swampy until forming the present lake about 600 years ago. The present day lake has only one outflow, the Utakura River, which flows into the Hokianga Harbour (Figure 1). The lake has a reasonably small catchment (2110 ha),which is a mix of dairying, drystock farming and lifestyle properties. The inflows into the lake are relatively small and include the Parakataio Stream, small unnamed streams and farm drains. The lake is shallow with an average water depth of 2 m, an annual seasonal variation of approximately 1 m and maximum depth of 2.6 m.

Lake Ōmāpere was vested to the Lake Ōmāpere Trust in 1954 by the Maori Land Court.The lake has considerable potential as an environmental, economic and recreational resource (LOT and NRC 2006). Lake Ōmāpere is an important taonga to Ngapuhi, as a source of torewai, tuna, raupo, kuta and harakeke. The mauri of the lake is linked to the well-being of the people. The lake and its catchment are also important ecologically, with several populations of the rare Northland mudfish in wetlands on the Lake margins and seeds of the rare native aquatic plant *Isoeteskirkii*found in the Lake bed sediments.

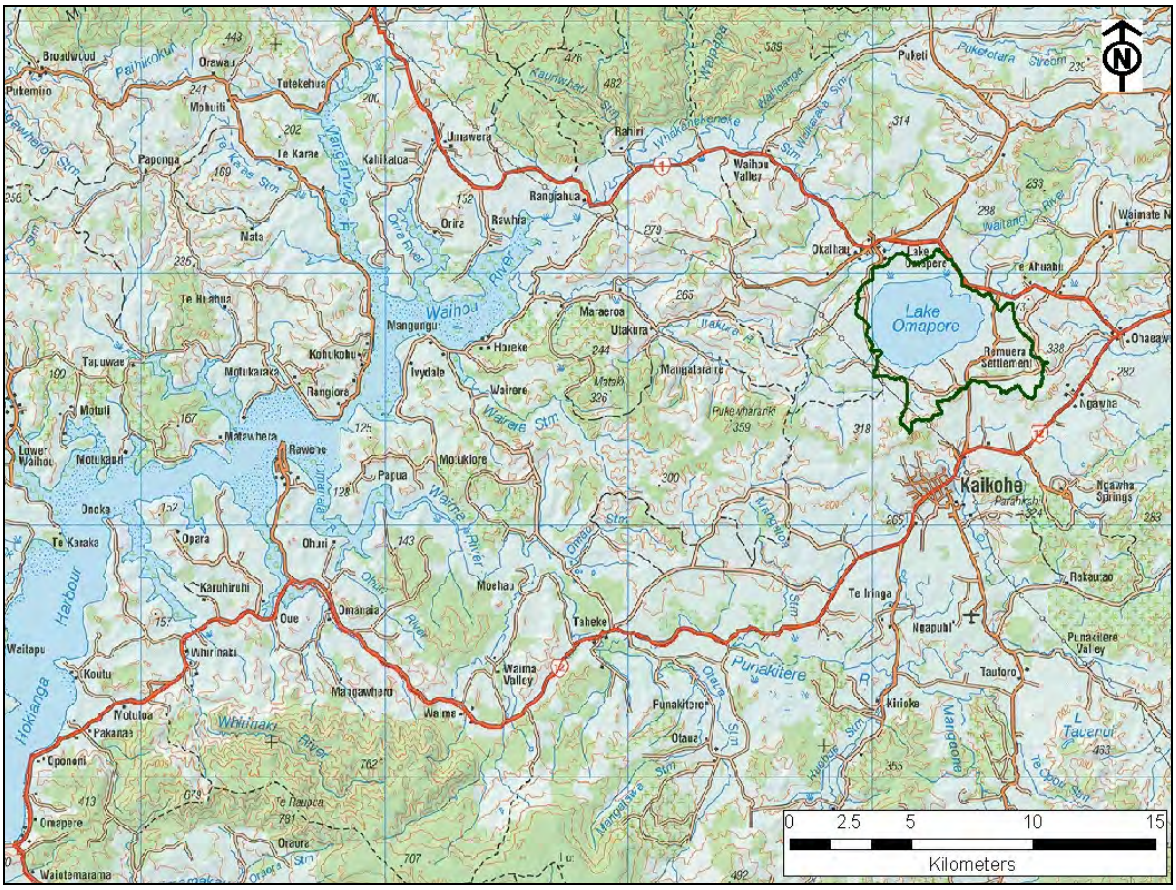

Figure 1: Map showing Lake Ōmāpere, the lake catchment and the only outflow, the Utakura River in relation to the Hokianga Harbour and Kaikohe township.

Problem prior to project

The lakehas been impacted by land use change and other human actions, including pastoral farming and drainage of wetlands, causing a decline in water quality (Verburg et al. 2012). The lake became highly enriched with nutrients. The lake was further degraded by the accidental introduction of oxygen weed(*Egeriadensa*) in the 1970s. The weed thrived in the enriched waters quickly covering the entire lake and smothering native plants.The weed attracted approximately 8,000black swans, which, although, would have contributed some nutrients to the lake, is likely to be minimal compared to the amount contained within the lake system (eg, in lake sediments and weed) and in the main is nutrient recycling (Bioresearches 2002).The oxygen weed collapsed in 1985 causing severe blue-green algal blooms. Algae reduces water clarity, forms surface scums, reduces oxygen and creates unpleasant odours. Blue-green algae can produce toxins harmful to humans, dogs and stock.The lake could no longer be used as the public water supply for Kaikohetownship, for stock water or recreational purposes (Champion and Burns 2001).Swan numbers reduced to an estimated 1,000 swans (Ray et al. 2006). Silver carp introduced into the lake in 1986 were unsuccessful in controlling the algal blooms.

The oxygen weed increased again covering the entire lake by 1999.The weed collapsed again in 2001/2002 and the algal blooms returned. The decaying oxygen weed caused low oxygen levels on the lake bottom which led to high mortalities of the freshwater mussels in the lake. Grass carp were released into the lake to control the oxygen weed in 2000 and 2002. The weed was completely eradicated from the Lake by 2003. However, the lake was still highly enriched and suffering from severe algal blooms, particularly in summer.

The poor water quality in Lake Ōmāpere has affected the Utakura River and Hokianga Harbour since the weed collapsed in 1985. The poor water quality has:

- made the Lake and River unsafe as water supplies
- affected food sources, such as tuna from the Lake and fish and shellfish from the River and upper Harbour
- led to restrictions onrecreational uses, such as swimming and wakaama.

Some restoration work had been completed prior to the project starting. For example, of 12 lake front properties visited in February 1992, one landowner had fenced and planted their lake frontage (Heaps unpublished) and two landowners had carried out substantial fencing and planting in the upper catchment of Parakataio Stream by November 1996 (Heaps unpublished and NRC 1996).

The Project

The Lake Ōmāpere Restoration and Management Project was a joint initiative between NRC and the LOT funded by the Ministry for the Environment's Sustainable Management Fund (SMF). According to the SMF contract the project officially started in December 2003 and ended in June 2006.

Project objectives

The overall aims of the project wereto develop and implement a voluntary lake management strategy that will work towards improving the health of the lake and help establish the Lake Ōmāpere Trustees in their role as Kaitiakitanga (NRC 2011a).

The project had five main outcomes (as set out in the SMF contract):

1. Development of a Lake Ōmāpere Management Strategy incorporating:-
2. Development of a weed management programme
3. Development of an integrated catchment management programme
4. Enhancement of indigenous biodiversity
5. Water quality monitoring and reporting.

However, through the project process the outcomes were modified to include a further outcome (NRC 2011b). The following main outcome was added:

6. Assist the trustees in their role as Kaitiaki for the Lake

In the SMF contract part of the first outcome included developing a Kaitiakitanga model and all five outcomes are important in assisting the trustees in their role as Kaitiaki. Therefore it is not surprising that this sixth outcome was added during the project process.

The approach taken for each of these outcomes is covered in the next section.

Approach taken

This section sets out the process followed to manage the project, consult with and gain feedback from key stakeholders and the process followed for each of the six main project outcomes as required by the SMF contract (see table 11 in appendix A for specific tasks).

Project management

Firstly, the Lake Ōmāpere Project Management Group (LOPMG) was established. The LOPMG included representatives from:

- Northland Regional Council (NRC)
- Lake Ōmāpere Trust (LOT)
- Te Runanga a Iwi o Ngapuhi(TRAION)
- Far North District Council (FNDC).

The group met regularly to progress the project.A Memorandum of Understanding (MOU) between NRC and the LOT,and a Communication Plan were established for the Project. The Communication Plan included key communication issues, objectives of the plan, key messages to be used in communications, key audiences and an outline of communication activity.

Progress reporting to MFE

As required by the SMF contract progress reports were provided to MFE every six months. These reports included progress on key tasks within the project and a summary of work completed over the six month period. These reports were an excellent mechanism for the LOPMG to monitor their progress against project milestones and where needed request variations to the original SMF contract, for example, due to delays in the SMF application being approved the project which was meant to start in July 2003 didn't start until December 2003, this lead to the final project completion date being shifted from January to June 2006. Four progress reports were completed in total (LOPMG 2004, LOPMG 2005a, LOPMG 2005b, LOPMG 2006).

Consultation

As stakeholder support and involvement was key to the success of the project, consultation was a critical part of the project. Key stakeholders included catchment landowners, Department of Conservation, local community, local schools, Ministry for the Environment, Research Institutes such as NIWA, Te PuniKokiri, Fish and Game New Zealand, New Zealand Landcare Trust and QE II (LOT and NRC 2006).

The first consultation was a Hui-a-Iwi held on 17 April 2004 at Mataitaua Marae, Utakura to introduce the project to interested Ngapuhi whanau, hapu and iwi representatives and to gain feedback (LOPMG 2004). Approximately 50 attendees identified their key issues and future visions for the lake.

Initially a letter was sent to all 41 landowners in the catchment in December 2003, followed by a phone call where possible. This was followed by individual meetings with 18 landowners in April 2004 to introduce the project, discuss the integrated catchment management process and to gain their thoughts on the issues and future visions for the lake.These visits were carried out by a Regional Council Land management officer and Lake

Omapere Trustees.Most landowners were not interested in public meetings, preferring consultation on a one on one basis and by letters or phone calls.

A public meeting was held on 1 July 2004 in Kaikohe to inform the community about the project and gain feedback on their issues and future visions for the lake and their ideas for restoring the lake.

The key issues and future visions for Lake Ōmāpere identified at the Hui-a-iwi, individual meetings with landowners and the public meeting are summarised below in Tables 1 and 2.

There was a second round of consultation held in January 2005 to:

- discuss the issues raised during the earlier consultation that were within the scope of the project and to look at options to address them
- update key stakeholders on the progress of the project
- introduce and seek feedback on a draft Lake Ōmāpere Management Strategy.

This consultation included three hui at MataitauaMarae, Te Ahuahu Marae and Kaikohe Memorial Hall, to ensure allwhanau and hapu areas were covered, and a public meeting in the Far North District Council Chambers in Kaikohe.

Information dissemination

There were several methods used to disseminate information and updates on the project, including the NRC website, a fortnightly project update given by a member of LOPMG on Radio Tautoko, pamphlets and letters to landowners, key stakeholders and interested parties and regular media releases announcing Hui and public meetings, planting days and warnings of algal blooms. Stakeholder, particularly landowners, and community support was key to the success of the project, so information dissemination was important to create awareness, interest and support.

Post project

This component of the project has been limited since the project finished. LOPMG stopped meeting regularly after the Strategy was launched, there has been no update of the NRC webpages and there has been very little information provided to landowners and other key stakeholders since 2006. Information sharing via the timeslot on Radio Tautokohas continued since the project finished (R. Henwood, LOT,pers. comm.).

Table 1: Summary of key issues raisedduring consultation (LOPMG 2004, LOPMG 2005a).

Key issues	Hui-a-iwi	Landowner meetings	Public meeting	Examples of comments received
Poor state of the Lake	+	+	+	
Multiple causes for the state	+	+	+	Natural factors, land use impacts and other human interventions
Impacts of the poor state	+	+	+	Loss of native plants and animals, water supply for humans and stock, human food resources and recreational opportunities
Impacts of farming	+	+	+	Removal of natural filtering systems, on-going impact of farming practices, lack of understanding of inflows and engagement with farmers, costs of fencing and spraying
Current management structures	+			Regulatory system has been ineffective, enhance kaitaikitanga and hapu management structures
Water level of the lake	+	+	+	Restore to historical level versus optimum level, need better information on effects
Lack of collective approach	+	+	+	Engage all different stakeholders, better communication, needs community support
Impacts of interventions	+	+	+	Interventions need to be well understood and managed eg carp, lake level
Lack of information	+	+	+	Good information on a timely basis, consistency
Actions taken by crown agencies	+			Lowering of the lake level, taking of land around the lake
Potential impacts of economic development	+			Agreed approach to economic development needed
Understanding bigger environmental picture	+	+		Linkage of Lake Ōmāpere with Ngawha Geothermal field
Balancing planning and action	+		+	Need for long-term planning but also quick action to avoid further problems
Voluntary process			+	Need compulsory participation, voluntary buy-in will lead to success

Table 2: Summary of future visions raised during consultation (LOPMG 2004, LOPMG 2005a).

Future visions	Hui-a-iwi	Landowner meetings	Public meeting	Examples of comments received
A healthy lake sustaining the people	+	+	+	Potential for economic development, plant riparian buffer strip around lake edge, healthy, sustainability
Lake Ōmāpere; Kaitakitanga in action	+			Restoration
Authority that supports hapu management and ensures compliance	+			Accountability
Lake Ōmāpere: A natural resource icon for Ngapuhi and Aotearoa	+			
A functioning Lake Ōmāpere community	+			Involvement, participation
A lake that can be used	+	+	+	Recreational use, to see wakaama on lake

Land management

This component of the project involved NRC staff and LOT working closely with landowners in the catchment. Land use in the catchment is a mix of dairy, dairy raising, drystock and lifestyles properties. In 2003, there was41 landowners in the catchment (LOPMG 2004), with approximately 15 of these adjoining the lake.Since 2003 there have been several changes in landowners, property boundaries (subdivision) and land use within the catchment eg, three dairy sheds on the south eastern side of the lake have stopped supplying (figure 2) with one now being a beef farm and the other was subdivided. Landowners with small lifestyle properties had minimal involvement with this component of the project. For all three dairy farms currently in the catchment their farm dairy effluent discharges (801413, 1218401 1229601, 1315201) are outside the catchment boundary (figure 2).

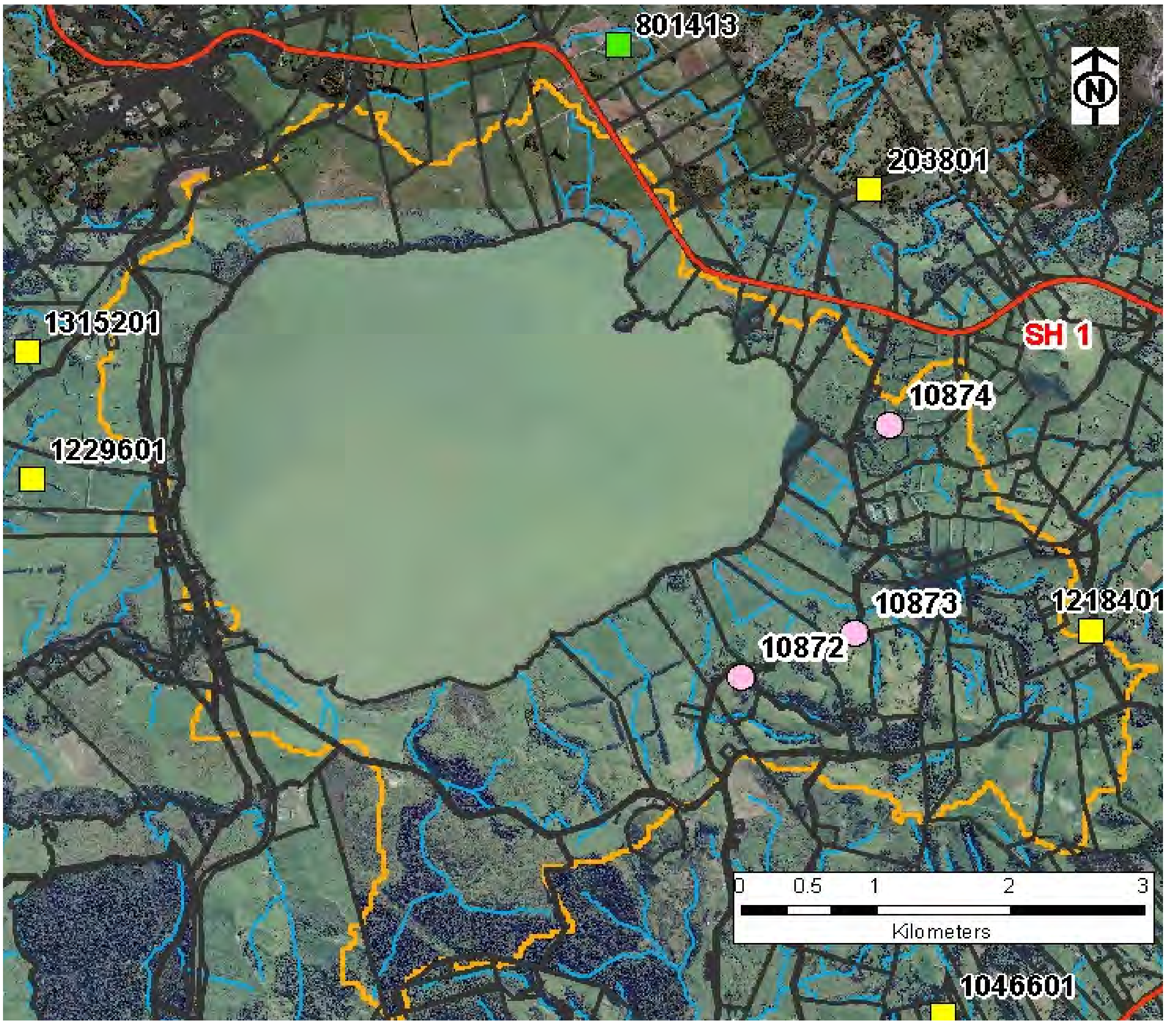

Figure 2: Map showing landowner boundaries in 2011 (black lines), catchment boundary (yellow line) and farm dairy effluent discharges,both current (yellow and green squares) and decommissioned (pink dots).

Farm plan process

Initially research was done on options for management plans and sources of information. This included contacting other Regional Councils regarding their environmental farm plan process, if any, and primary industries to assess industry initiatives and resources available. This information was collated and reviewed to determine a process appropriate for the Lake Ōmāpere Project. The following process was decided on:

- a NRC land management officer and Lake Ōmāpere Trustee representative worked with the landowner and/or manager
- the concept of farm plans was introduced and discussed
- a brief property questionnaire was completed by the landowner
- the property was mapped into Land Management Units (LMUs), land uses and activities recorded
- a draft plan of the property was prepared, including maps and sections focusing on social responsibility, animal health and production, and land and environment
- industry resources were used, such as nutrient budgeting by fertiliser companies
- theplan was finalised with maps and an action plan of works as agreed with the landowner.

The LMUs were developed at the paddock scale using all available information such as landowner knowledge, soil and rock type, land contour and aspect, limitations to land-use (eg erosion and seep areas) and significant sites. This was done by the NRC officer and Lake Ōmāpere Trustee(s) walking around the property with the landowner (if possible). The following was also discussed with the landowner: management factors, such as grazing and effluent application; fertiliser use, including nutrient budgets and code of practice; soil health; biodiversity and riparian management. All farmers involved in the process agreed to have a nutrient budget developed by their fertiliser supplier using the OVERSEER model.

The farm plans developed were based on the land and environmental component of the FarmSure plan (previously called Project Green), adapting it to individual property needs. Key factors identified to ensure the success of the farm plans were the need for:

- high farmer involvement in plan development to ensure it was practical and useful for the landowner
- a quick turnaround so momentum was not lost with landowners
- the tailoring of information in the plans to the different property types, dependant on what the landowners wanted
- flexibility in the timing of tasks to suit landowners.

As mentioned above, 18 of the 41 landowners in the catchment were visited in April 2004. These 18 properties account for about 90% of the catchment area. For 3 of the 18 properties farm plans were not relevant due to property size and location. Of the 15 remaining properties visited in April 2004 11 agreed to being involved with the farm plan process, 3 wanted to wait to see how the project progressed first and 1 was not interested. The 23 landowners not visited, accounting for 10% of the catchment area, were sent a letter and brochure. The majority were small properties, however 3 were farmers. Two landowners responded that they were not interested and the rest did not respond.

Nine properties were mapped between October and December 2004 inclusive. By January 2006, 13 of 19 farms in the catchment had been or were in the process of being mapped, accounting for 93% of the catchment. Two farm plans were completed to draft stage by March 2008.

Nutrient budgets were developed for each farmer by their fertiliser supplier. NRC then paid for a contractor to review these nutrient budgets in 2005/2006. A review report was produced for each farmer.

Riparian fencing

There was substantial fencing to exclude stock from the lake margins, wetlands, streams and farm drains carried out during the project. The fence type varied from single and two wire electric fencing to seven wire post and batten fences. The cost of fencing was covered by a range of sources including NRC Environment Fund, FNDC Significant Natural Areas Fund, Nga Whenua Rahui and landowners (both capital costs and time).

Riparian planting

To maximise the success of plantings undertaken in the catchment, the plants used were predominately grown from locally sourced seeds. Seed gathering began in November 2005, with the collection of half a bucket of puriri seeds, which were propagated in the DOC nursery. It was recommended that all seeds be collected from the Kaikohe Ecological District, except for the wetland plants such as harakeke and manukawhich should be collected from around the lake. A seed gathering timetable was developed (Table 3).

Table 3: Seed gathering timetable developed in 2005

Plant	When
Toetoe	Nov – dec
Harakeke	Jan - feb
Totara	Feb – mar
Ti kouka	Feb – mar
Kahikatea	Feb – apr
Manuka	Mar – may
Taraire	Apr – may
Kauri	Sep – nov
Kuta	TBA
Raupo	TBA

Seeds were propagated in the DOC nursery, lakeside nursery and nursery in Rawene (the latter two both operated by Lake Ōmāpere Trustees) and ashadehouse in Kerikeri. Splitting of harakeke was also used as a source for new plants.

All planting was carried out by volunteers, either at community planting days, by school groups, landowners, Conservation Corps,Corrections Department Community Service Workers or Lake Ōmāpere Trustees. Two community planting days were held in August 2005 with approximately 60 volunteers at each and over 3,200 plants in total being planted.This included flax, cabbage trees, hoheria, titoki and karaka. One was planting out a newly fenced area on the northern lake margin and the other was planting around the Utakura River at the outlet.

Three community planting days were held in July 2006, which included planting fenced lake margin on two properties, planting a fenced wetland area on another property and further planting at the outlet (LOPMG 2006b). Northland College students also held two planting days on the lake margin on a different property again with over a 1,000 plants in total going in the ground. The bulk of the plants were harakeke that had been split from large plants on the lake edge. The splitting was done by Corrections Department Community Service Workers and other volunteers.Conservation corps assisted with planting, particularly in areas inappropriate for public planting days or school groups.

Weed and pest control

New Zealand Landcare Trust (NZLCT) and NRC staff presented on different approaches to pest control including community pest control areas to landowners and other key stakeholders at the celebration evening held in June 2006 (LOPMG 2006b). There has been some possum control and weed releasing in areas planted in 2005 (LOPMG 2006b, R. Henwood, LOT, pers. comm.). Otherwise, there has been very little weed and pest control (NZLCT unpublished).

Other work

Soil workshops held in December 2005 were attended by farmers in the Lake Ōmāpere catchment. The focus of the workshops was learning how to visually assess soil health and different management techniques to improve soil health. A further series of workshops were held in November 2006. The workshops were run by a soil scientist (Graham Shepherd) with support from NRC.

Key stakeholders were invited to a field day organised by the Farm Forestry Association in October 2006. The field day covered possum and predator control, riparian management and productive uses of farm grown totara.

Post project

NRC contracted the drafting and completion of the farm plans in 2008/2009 building on the mapping done during the project. Farm plans were finalised for a further eight properties in the catchment.

Community planting days and planting by other volunteers has continued every year since the project finished. About 30 volunteers helped at two community plantings days held in June 2007 on two properties on the southern lake margin (NRC 2007b). Unfortunately high lake levels meant that planting days in July had to be cancelled (NRC 2007c). Also in 2007, inmates from Northland Corrections Facility grew and planted 1,000 native kanuka seedlings and split thousands of flax ready for planting (NRC 2007a, NRC 2007d). In 2008 over 20 volunteers planted about 1,000 split flax plants in June but the second planting day in August had to be cancelled due to the property being too wet (NRC 2008).

Aquatic weed management

The management of aquatic weeds component of the project involved: surveys of the aquatic weeds in the lake and catchment waterways, research of management options and management of problematic weeds found, estimates of grass carp numbersremaining and the development of a weed management programme.

Aquatic weed surveys

These surveys were carried out to determine whether *Egeriadensa* or any other invasive aquatic plants were present in the lake or catchment waterways and if so where and to what extent. A lake survey was carried out by NIWA in April 2004 using both the sonar system on the boat to map weed cover and a diver using a 1 m^2 quadrant to estimate biomass. No plants were found.Further dive surveys of the lake were carried out in November 2004 and December 2005, again with no plants found. Detailed changes in *E. densa* biomass are included in the current state of the lake section of this report.

A survey of all significant catchment streams and farm drains was carried out by NRC staff, Lake Ōmāpere Trustees and other volunteers in November 2004. This involved walking the length of these waterways and recording any aquatic plants found. No plants of the four invasive oxygen weeds found in New Zealand were recorded.A follow up survey of the catchment streams and drains was carried out in March 2006. No new plants were recorded from what was found in the 2004 survey.

Six strands of what appeared to be *E.densa*were found on a fishing net covering the mouth of a farm drain at the southern end of the Lake by the grass carp contractor in December 2004 (LOPMG 2005a). However, identification was never confirmed and no plants have been found in any of the lake or catchment weed surveys, mussel surveys, fish surveys or during water quality sampling since. Other than the six strands, no plants have been found on fishing nets by the grass carp contractor or eel fisherman since 2002.

Management of problematic weeds

The only two plants found that were identified as being potentially problematic were the swamp lily *Otteliaovalifolia* and alligator weed. *Ottelia* was found in two small areas in Parakataio Stream and was identified as a priority for eradication by NRC biosecurity staff (LOPMG 2005a). The best method for controlling *Ottelia* is manually removing it by hand. Plant removal was carried out by NRC staff and Lake Ōmāpere Trusteesin May 2005, by divers in December 2005 and in March 2006 during weed surveys, after which more plants still remained (LOPMG 2005b, LOPMG 2006). However, NIWA have since advised that *Ottelia* is a relatively benign plant and that control is not necessary (Ray et al. 2006)

Options for the control or eradication of alligator weed were investigated. Options were found to be mechanical harvesting, herbicide sprays or biological control. Biological control was the option chosen. Fortunately, the alligator weed beetle (Agasicleshygrophila) one of the biological control agents that has found to be relatively successful at controlling alligator weed to stop it from causing thick floating mats was found in the catchment at the lake outlet and Parakataio Stream (LOPMG 2005b).

Grass carp numbers

A total of 60,643 grass carp were introduced into the lake in 2000 and 2002 to manage the oxygen weed. A key component of the weed management part of the SMF project was to estimate the number of grass carp remaining in the lake, as their presence is vital to guaranteeing the oxygen weed does not re-infest the lake or even worse reach the point where the weed beds collapse. LOT gained a special permit from the Ministry of Fisheries to remove grass carp from the Lake in October 2004. The permit required the permit holder to provide monthly returns of the number of carp removed. The permit expired in September 2007.

To estimate the number of grass carp remaining research into grass carp mortality rates was carried out and the monthly returns of the number of carp removed were summarised (LOPMG 2005b). It was very roughly estimated that approximately 11,000 carp remained in the lake at the end of the 2006 summer, excluding carp removals. Based on the monthly returns available, 2078 grass carp were removed from the lake between October 2004 and June 2006, leaving an estimated 9,000 carp in the lake.It is likely that there have been many more grass carp mortalities since the end of the 2006 summer through disease and starvation, however how many is unknown. So a conservative estimate of the number of carp remaining in the lake would be 9,000.

There is no doubt that there arestill grass carp in the lake. Carp have been seen recently in the shallow bays of the lake and in catchment streams (R. Faithfull, catchment landowner, and E. Simpson, NRC, pers. comm.) and have also been seen in the lower reaches of the Utakura River (R. Henwood, LOT, pers. comm.). Grass carp introduced into Lake Elands in Hawke's Bay in 1988 survived with very little food for at least six years. The last single plant of the invasive weed *Hydrilla* was found in 2003. With very little food sources available carp caught in 2004 were still healthy and were found to be feeding on willow leaves (P. Champion, NIWA, pers. comm.). About 30 of the 400 grass carp released remained in the lake in 2008 (The Dominion Post 2008).

Weed management programme

The grass carp and aquatic weed management programme was finalised by July 2005. The recommendations from this programme provided the key actionsfor aquatic weed management in the Strategy. These actions are to undertake:

- aquatic weed surveys in the lake every two years
- aquatic weed surveys of the waterways leading into and out of the lake and the lake margins annually
- public awareness and education via radio and other media on spread of aquatic weeds annually
- erecting signs at main entry point to lake warning against the spread of weeds and updating every five years
- a review of the aquatic weed management programme every five years.

As recommended in the weed management programme, signage was erected at the two main entry points to the lake (the launch site and at the outlet) in 2006. A visit to the lake on 30 October 2011 showed that the sign at the launching site was still clearly visible and in good condition, however, the sign at the outlet had been pulled down and damaged.

There appears to have been very little public awareness and education on the spread of aquatic weeds. One brochure in September 2006 advised key stakeholders of the two signs being erected and created awareness about the potential ways that invasive weeds such as E. densa could get into the lake and/or catchment. Awareness has been carried out during the panui on Radio Tautoko(R. Henwood, LOT,pers. comm.). There appears to have been no media releases to create awareness about the spread of weeds in 2006 or 2007 as planned (LOPMG 2006a).

Post project

Further surveys of aquatic vegetation in the lake were carried out in October 2007 and October 2010, with no plants found. A brief check was also done in November 2011, with no *E. densa* or other invasive plants found.

There have been two recent media releases in relation to weed control in other Northland lakes, which contained clear messages about the risk of spreading weeds (NRC 2009 and NRC 2010).

Enhancing indigenous biodiversity

As part of this component of the project, research into existing and historical indigenous biodiversity was done. The findings are incorporated into the current state of the lake section of this report.

Freshwater mussels

During the project, surveys of the freshwater mussel (*Hyridellamenziesi*) population in the lake were carried out in April 2004, November 2004 and December 2005. The surveys involved several sites (number varied with survey) throughout the lake. At each site, the mussels found in each of five 31 x 31 cm quadrats (0.1 m^2) were bought to the surface by adiver. Live mussels were counted, measured and then returned to the water.In April 2004 six sites were surveyed (Champion 2004).In November 2004 and December 2005,17 and 22 sites respectively, were surveyed to roughly map the extent of the mussels within the lake (LOPMG 2005a, LOPMG 2006). The results from these surveys were used to determine the mussel distribution in the lake and changes in mussel densities and population structure (mussel sizes). The results are presented in the current state of the lake section.

Research to assess the feasibility of mussels being used to improve water clarity in the lake was carried out. Background information including details on their parasitic life stage, reproduction and growth rates, factors that affect mussel densities and filtering rates was summarised (LOPMG 2005a).As part of this, a model for the filtering ability of mussels in Lake Ōmāpere was calculated. It was estimated that an average of 35 mussels/m^2 in the Lake would be able to filter the entire water column in one day, thus controlling algal levels.

As part of this research, proposals were made for two experimental trials (LOPMG 2005a). The first,proposed setting up cages with mussels from the north of the lake, in the centre and south of the lake, to determine what is influencing the survival and recruitment of mussels. This experiment was never carried out due to iwi concerns with relocating mussels. The second experiment proposed establishing a small enclosure to determine whether water clarity could be improved to the point where aquatic plants could be introduced. This enclosure was established in June 2005 at the northern end of the lake and strengthened in December 2005 (LOPMG 2006a). The enclosure was checked during sampling visits. The enclosure remained in the lake for about a year but no improvements in water clarity within the enclosure where seen during this time. It was noted that the enclosure was possibly too flexible and that a more solid structure, such as a rock groyne, may have been more successful at restricting re-suspension of the lake sediments.

Fish

Research into historical records of both native and pest fish in the lake was done, using reports and the New Zealand Freshwater Fish Database (NZFFD) administered by NIWA. Consultation was also done with the carp and eel fishermen, NRC and NIWA staff, Lake Ōmāpere Trustees and landowners to record any fish observed.

The pest fish previously recorded in the lake of most concern were catfish and mosquito fish. Catfish were caught in eel fishing nets in 2001 but had not been caught or seen since (LOPMG 2005a). Mosquito fish had been recorded in the lake but there current status was unknown. The status of two native fish species previously recorded in the lake, common bully and smelt, was also unknown.

A fish survey was carried out by NRC and LOT in May 2005. No mosquito fish, catfish, common bully or smelt were caught or seen during this survey. More detail on the fish recorded in the lake and catchment is presented in the current state of the lake section.

One SMF project task required the development and implementation of a pest fish management strategy, however, the research and fish surveyshowed there were no populations of pest fish currently in the lake that needed management. Recommendations were made to continue routine fish surveys to check for both native and pest fish species. The action in the strategy “Undertake freshwater fish surveys” is “as required”.

Aquatic plants

As for other indigenous biodiversity, research into aquatic plants previously found in the lake was done (LOPMG 2005a). As discussed above, surveys for aquatic plants by divers were carried out in the lake in April 2004, November 2004 and December 2005. The lake was completely de-vegetated, with no native or exotic plants found. During the plant surveys of the catchment streams and drains in November 2004 and March 2006 one native aquatic plant was recorded as extensive throughout the catchment, *Potamogetonchessmanii*.

Sediment samples were collected by NIWA from six sites in April 2004 to assess potential seed bank presence within the lake (Champion 2005). At each site two sets of five sediment cores were collected by divers. The samples were set up in troughs under 0.8 m of water and 92% neutral density shade cloth. The samples were inspected for germination on four occasions up to and including January 2005. A total of 25 plants germinated between April 2004 and January 2005 (Table 4), with all but the two *Nitella*plants and one *Charaaustralis* not survivingto January 2005. From this estimates for the number of viable seeds in the lake can be made. In the lake centre there would be approximately 26 charophyte propagules per m^2 (*C. australis*). In the shallows (north and south) there would be approximately 44 charophyte propagules per m^2 and 53 turf plants (*Nitella*, *Glossostigmacleistanthum*, *Elatinegratoiloides*).

Table 4: Plants that germinated between April 2004 and January 2005 from sediment cores taken from Lake Ōmāpere (Champion 2005)

Species	2 north sites	2 centre sites	2 south sites
Charaaustralis	1	3	9
Nitella sp.	2		
Glossostigmacleistanthum	2		3
Elatinegratioloides			5

The samples were inspected on two further occasions in 2005 and all plants propagated for future restoration projects in the lake. Some of these plants were taken to the lakeside nursery in August 2006 to eventually be planted out in the lake when conditions improved but did not survive. Presumably NIWA still have the remaining plants.

Other biodiversity

Very little was done in terms of other biodiversity in the lake and catchment as the tasks within the SMF project focused on freshwater mussels, native aquatic plants andpest fish. Research was done into historical records of aquatic invertebrates, birds and terrestrial biodiversity (LOPMG 2005a).

Riparian planting efforts have substantially enhanced the terrestrial plant biodiversity, in turn providing more habitat for fauna. Details on the actions taken for seed collecting and propagation, riparian planting and weed/pest control are covered above under land management.

Post project

Further surveys of the mussels and aquatic vegetation in the lake were carried out in October 2007 and October 2010. Further fish surveys were carried out in January 2007, November 2009 and November 2011 by NRC and in November 2008 by NIWA on behalf of the Utakura Environmental Group.

Water quality monitoring

Lake water quality monitoring

Water quality monitoring was carried out throughout the life of the project in a similar capacity to the Regional Councils existing monitoring programme. The Council has been monitoring the lake since 2001 and prior to this, it had been sampled by NIWA since 1992 (NRC 2006). Monitoringwas usually monthly or every second month. Samples were taken at two locations near the centre of the lake at both 25% and 75% depth (sites 106460, 106461, 106462 and 106463) and from the Utakura River at the lake outlet, site 100501 (Figure 3).

Figure 3: Map showing sampling sites in lake (yellow dots) and catchment (green dots) with outlet site 100501 also in green. Some of catchment boundary can be seen (dark green line).

Measurements for temperature, dissolved oxygen, conductivity and water clarity were carried out in the field and samples collected for testing in the laboratory. Samples were analysed for pH, suspended solids (total and volatile), nutrients (total nitrogen and total phosphorus), chlorophyll a and algae identification. The identification of algae species with ranking of the most abundant species, cell counts for blue green algae and testing for toxins produced by the blue green algae was started in December 2003.

Lake Ōmāpere Trustees and other interested stakeholders assisted with water quality monitoring on several occasions during the life of the project.Northland College gained funding from the 2006 NRC Environmental Curriculum Award. Year 9 students investigated how the water quality of Lake Ōmāpere has deteriorated through human impacts and how this impacts on local iwi. This included the students listening to guest speakers, visiting a farm, plant nursery, the lake, collecting data and reporting on their findings.

Other monitoring

NRC carried out adhoc sampling of catchment streams and farm drains on four occasions during the project (Figure 3). These sites were typically sampled for dissolved and total nutrients (NRC 2006), as well as the usual field measurements, such as temperature and dissolved oxygen.

NIWA was contracted by the LOPMG to carry out a one-off groundwater survey to assess the likely groundwater inputs of nutrients to the lake and identify localised areas where groundwater inputs may have an adverse impact on lake water quality. The survey was carried out over three days in May 2006 (Gibbs and Mackay 2006). Sampling was attempted at about 56 locations around the lake (at approximately 200 m intervals) but in many instances it was not possible to sample due to the nature of the soils. A groundwater sample was collected within 5 m of the lake edge using a penetrometer at about 18 locations around the lake. At about 20 locations samples were collected from streams and farm drains. These surface inflows are considered to be representative of shallow groundwater. These samples were analysed for the dissolved nutrients: dissolved reactive phosphorus (DRP), ammoniacal nitrogen (NH_4) and nitrate nitrite nitrogen (NNN).

Sediment samples were collected during mussel surveys in November 2004 and December 2005 from four locations in the lake: sites 106462, 107882, 108244 and 108246 (Figure 3),andanalysed for nutrients (NRC 2006).

For results from the lake and catchment water quality monitoring, groundwater survey and sediment sampling refer to the current state and trends section of this report.

Post project

Since the project finished, lake sampling has been slightly more irregular and sampling at the two 75% depth sites ceased in September 2008. Catchment streams have been sampled on several more occasions and sediment samples have been collected during mussel surveys in October 2007 and October 2010.

Kaitiakitanga

Quite early on in the project after some discussion on what kaitiakitanga meant and research of existing models it was decided that kaitiakitanga should be the overarching model and that the detail of the strategy should sit within this (LOPMG 2004). It was also agreed that given the breadth of kaitiakitanga, some management issues sat outside the LOPMG brief and that ultimately implementation of kaitiakitanga resides with the LOT, such as the original lake level and boundary issue.

Research into strategies and kaitiakitanga models developed elsewhere in New Zealand was carried out (LOPMG 2004). It was found from an ecological [sic environmental] and management perspective Lake Ōmāpere is not unusual.There are similar examples within New Zealand, such as Lake Horowhenua, Wairewa and Waihora, with Horowhenua being the most comparative to Lake Ōmāpere.

Kaitiakitanga is discussed further below in strategy development.

Post project

As the issue of the original lake level and boundary continued to arise throughout the project and potentially couldeffect the success of future actions such as planting of lake margin areas, LOPMG determined that a legal survey of the lake boundary was a priority for progressing the restoration of Lake Ōmāpere. The NRC agreed to fund a full survey of the boundary of Lake Ōmāpere at the 17 May 2006 Council meeting. The legal survey was carried out in August 2006bydemarcating the legal boundary of Lake Ōmāpere as shown in green on the 1923 survey plan SO 22379. Demarcating involved placing survey pegs on a straight line interpretation of the green line, which is shown as a wavy natural boundary. This showed that the current day lake level is very close to the 1923 level in most areas of the lake. There are some areas where the 1923 boundary was in the water in August 2006 and other areas where the 1923 boundary was in amongst vegetation on the land. The resulting survey plan T10155 was lodged with Land Information New Zealand.

Strategy development

The strategy was developed by the Lake Ōmāpere Trustees on the LOPMG with assistance from NRC policy staff. There were many iterations of the draft strategy. An early draft was made available at the Hui and public meetingin January 2005 for feedback (LOPMG 2005a). However, a number of issues with the structure and format of this early draft were raised (LOPMG 2005b). One of the main issues was who the strategy was being prepared for, who would administer the strategy over time, ensure its actions were being achieved and undertake its review. Without this the strategy was unlikely to survive long past the end of the SMF project. After much discussion it was agreed that the Lake Ōmāpere Trustees, as owners of the lake, are inherently responsible for this. However, it was recognised that community, local and central government support were also critical to the success.

A second issue that was raised about an early draft of the strategy was that it contained little about the concept of kaitiakitanga as it relates to Ngapuhi-nui-tonu even though this was the basis of the SMF application. As mentioned above, LOPMG believed kaitiakitanga was crucial to the strategy and therefore time was spent refining the strategy to not only incorporate the concept of kaitiakitanga but to have this as the main framework of the strategy.

There was also discussion on whether the visions for the lake could be shared by all and it was decided that this was not the case and that the strategy needed to include the visions for the lake gained from the hui, public meeting and landowner meetings as well as those of the LOT. A version of the draft strategy that addressed these issues was provided to MFE in the 3rd progress report in July 2005 (LOPMG 2005b).A similar version of the draft strategy was presented to a meeting of the Lake Ōmāpere Trustees on 15 September 2005 for endorsement and/or feedback and provided to the Planning and Policy Committee on 21 September 2005 for their information.

Unfortunately the LOT was the subject of a Maori Land Court application in 2005/2006 and this delayed the finalising of the strategy. However, in 2006 the LOT held several workshops on the strategy to ensure all Lake Ōmāpere Trustees completely understood and agreed with its contents. The draft Strategy was further modified as a result of those workshops and the resulting final draft was approved by the LOT. This final draft Strategy was then put to the NRC Planning and Policy Committee on 20 September 2006 for approval on behalf of the Northland Regional Council. The Committee recommended that the strategy be approved for signing by the NRC chairman on behalf of the NRC.

The final *Restoration and Management Strategy for Lake Ōmāpere*was officially launched at a celebration evening on 29 September 2009 at ParawhenuaMarae, where it was formally signed by the chairmen of the NRC and LOT.

The final Strategy document includes sections on:

1. About the Lake – including the history and importance of the Lake
2. Issues - a summary of the issues raised through the consultation
3. Managing the future of the Lake – a brief introduction into the structure of the strategy

4. Waiora – the overall vision for the lake and by reaching this, the other visions that will be achieved
5. Kaitiakitanga – explains the concept of kaitiakitanga and the four elements important to achieving waiora
6. Actions – the actions which collectively need to happen to improve the health of Lake Ōmāpere

The four elements required to achieve waioraare:

- Ki utaki tai – the total connectedness of the natural environment
- Matauranga – the knowledge that underpins kaitiakitanga
- Rangatiratanga – the sense of authority, control and responsibility inherent in exercising kaitiakitanga
- Kotahitanga – unity of purpose.

Within these four elements there are 19 actions, such as water quality monitoring, aquatic weed and pest fish management, improving the knowledge base and information sharing, and training. Within each of these 19 actions there are many individual actions, who will undertake the actions and an indicated date of when they will be done. LOT and NRC have the lead role in all actions but other stakeholders are acknowledged as important to the success of the strategy. For more detail on the actions refer to Table 12 in Appendix B.

What was achieved?

It is difficult with many of these to determine exactly when they were completed and even though many of them were finished after the project officially finished it was due to the project that they were completed so have still been included below.

Strategy

The *Restoration and Management Strategy for Lake Ōmāpere* was signed and launched on 29 September 2006.Some actions in the Strategy have been completed but these have in the main been business as usual rather than someone actually referring to the strategy to guide action.Examples include water quality monitoring by NRC, fish surveys by NRC and LOT, further fencing and planting by landowners and LOT. For more detail on what actions have been carried out refer to appendix B.

On the ground

The land area covered by landowners that were moderately to heavily involved in the project makes up 90% of the catchment (LOPMG 2004). A further14 landowners (< 2% of the catchment) were informed of the project but not involved as they have small lifestyle properties and/or were located so far back in the catchment they have no or very minimal impact on the lake.

Farm mapping has been carried outfor 14 landowners (about 72% of the catchment) and farm plans were finalised for eightlandowners and drafted for a further two(about 45% of the catchment in total).

By June 2006, about 40 km of fencing had been completed to exclude stock from waterways including the lake (it is not clear but this is likely to include fencing carried out prior to the project starting). It was estimated that a further 30 km was required to exclude stock from all waterways in the catchment (LOPMG 2006b). By February 2007 about 15km of the lake's margins across nine properties had been fenced since the summer of 2004, with another roughly 3km scheduled for completion in 2008 (NRC 2007d).

In 2011, it is estimated that over 54 kilometres of fencing in total has been carried out to exclude stock from the lake, streams, drains and wetland areas. In total 17.5 kilometres of fencing has been erected around the lake margin to exclude stock from the lake, lakeside bush and lakeside wetlands. This includes wetlands that contain the rare Northland mudfish. Approximately 84% of the lake margin is now fenced with only two landowners that have not fenced their lake margin, totalling 2.6 km.

From 2005to2008, there wasat least 11 planting days held, with over 250volunteersin total assisting with planting, including landowners, schools, Lake Ōmāpere Trustees, Conservations Corps, Corrections Department Community Service Workers and other volunteers. Between 2005 and July 2007 organised planting days had led to an estimated 10,000 plants being put in the ground around the lake's margin (NRC 2007b) and many more have been planted outside of planting days and since 2007.Site visits in 2008 to areas planted in 2006 and 2007 showed a relatively high survival rate of plants, particularly harakeke (NZLCT unpublished).

Seed collection and flax splitting has been carried out on many occasions since 2005. Two nurseries have been established to propagate seeds collected and they grow a range of native plants for the catchment.

Since the project finished, there has been on-going fencing, planting and weed clearance by landowners, Lake Ōmāpere Trustees, Northland College students and other volunteers.

On-going monitoring

Between 2004 and 2011, there have been five surveys of the plants and mussels in the lake, two aquatic plant surveys of the catchment streams and drains and five fish surveys.

Between December 2003 and September 2011 lake water quality has been sampled 64 times, sediment samples from the lake bed have been collected on 4 occasions, shallow groundwater has been sampled once and various catchment streams and drains have been sampled on 10 occasions.

What funding and resources were used?

As with most projects of this nature it is difficult to accurately calculate all costs. Many inkind contributions of time go unrecorded, as do some capital costs, such as fencing undertaken at landowners expense. The figures provided below will be an underestimate of the total cost.

Labour resources

This presents time spent on Lake Ōmāpere and its catchment by the Regional Council and other key stakeholders. Particularly for other key stakeholders this is likely to be an underestimation of time spent.

Regional council labour

NRC gave substantial staff resources to the Project, including time from monitoring, land management and policy staff (Table 5). From 1 July 2003 to 30 June 2006 (similar to project period) a total of 5,614 hours were recorded for work on Lake Ōmāpere by Regional Council staff. This equates to over one Full Time Equivalent (FTE) for the three year period. Based on council charge out rates this equals over $333,000 given in staff time.Although the project officially finished in June 2006 (ie, SMF funding ceased), as discussed above, substantial amounts of project work continued into the next year. This is shown in the 1237 hours spent from 1 July 2006 to 30 June 2007 (approximately 0.7 FTE). Hours spent on Lake Ōmāpere reduced dramatically after this. It is valuable to note that the hours spentbetween July 2009 and June 2010 were all monitoring staff hours (ie, no policy or land management staff hours).

Table 5: NRC staff time spent on Lake Ōmāpere and its catchment. Monetary value is based on NRC charge out rates.

Council year	Total hours	Total amount (NZ$)
Jul 03 to Jun 04	1198	68366
Jul 04 to Jun 05	2470	143766
Jul 05 to Jun 06	1947	121021
Jul 06 to Jun 07	1237	76440
Jul 07 to Jun 08	547	32878
Jul 08 to Jun 09	168	12273
Jul 09 to Jun 10	131	9355

Other keystakeholders

From 1 July 2003 to 30 June 2006 an estimated 2,483 hours were recorded as inkind time given to the project from FNDC, Lake Ōmāpere Trustees, TRAION, DOC, Radio Tautoko and other volunteers (Table 6).

Table 6: Estimated inkind time (hours) contributed to Project by Lake Ōmāpere Trustees and other key stakeholders from July 2003 to June 2006

Financial year	FNDC	LOT and other volunteers	TRAION	DOC	Radio Tautoko	Total
Jul 03 to Jun 04	94	94	5.5		5	198.5
Jul 04 to Jun 05	64.8	306.5	70		7	448.3
Jul 05 to Jun 06	39	1588	12	190.8	7	1836.8

Capital costs

Regional council costs

From 1 July 2003 to 30 June 2006 (similar to project period) a total of $171,885 (excluding GST) was spent on Lake Ōmāpere by the Regional Council (Table 7). Note a substantial amount of these capital costs for the project were reimbursed to the Council as funding from the SMF fund (see below). These costs exclude NRC Environment fund grants given to applications pertaining to the Lake Ōmāpere catchment. Again, there were substantial contributions from the council post project. For example, $42,670 was used for the legal survey of the lake boundary in 2006/2007 and $28,975 was used for the completion of the Farm Environment Plans in 2008/2009.

Table 7: Capital costs for Lake Ōmāpere and its catchment from July 2003 to June 2010. Excludes Environment Fund grants (see table 8).

Year	Vehicle and boat running costs	Sample testing	Consultants/ contractors	Sundry supplies	Publicity/ education	Total
03/04	0	4930	27824	36	0	32790
04/05	6298	7136	38548	3026	612	55621
05/06	13501	12333	55587	1815	238	83474
06/07	5984	8425	43916	250	0	58574
07/08	2270	5605	2334	0	2500	12710
08/09	1850	4112	26594	0	2631	35186
09/10	1922	4533	1064	0	0	7518

NRC Environment fund

NRC Environmental Fund typically contributes up to 50 percent of the total cost of a project (labour costs can count towards the landowners contribution) – all of which must be of long-term benefit to the local environment and show clear evidence of good resource management. Between 2004/2005 and 2007/2008 13 applications for work in the Lake Ōmāpere catchment were successful at gaining support from the Environment Fund to a total of $74,240. This excludes the landowners contribution or other sources which must be at least 50% of the total cost.

Table 8: Environment Fund grants used for restoration work in the Lake Ōmāpere Catchment

Year	Total	Projects
2004/05	$14,200	Establish nursery Contribution to differentnursery for plants for 2005 planting days 1 km of fencing and planting - bush and wetland in upper catchment of ParakataioStrm 1.2 km of fencing and water supply – northern lake margin including bush remnant 2.1 km of fencing – south eastern lake margin including bush remnant
2005/06	$43,550	250 m of fencing and enhancement of wetland – northern lake margin 800 m of fencing – wetland, stream, swamp and portion of ParakataioStrm 1.25 km of fencing – eastern lake margin including wetland and bush 8 km of fencing – drains and streams on south eastern end of lake 1.6 km of fencing – stream, wetland and gully on northern end of lake
2006/07	$13,030	1.3 km of fencing – eastern lake margin 3 km of fencing – drains and streams in southern end of catchment
2007/08	$3,460	700 m of fencing – eastern lake margin, wetland and stream

Some of these projects also received contributions from other sources such as DOC, Fonterra, FNDC and the National Biodiversity Condition Fund. For example, between 2004 and February 2007, a total of about $160,000 was spent fencing the lake's margin, including funding from landowners, the NRC, FNDC, NgaWhenuaRahui and the National Biodiversity

Condition Fund funding (NRC 2007d). For more details on FNDC and NgaWhenuaRahui contributions see below.

Other key stakeholders

Between July 2003 and June 2006, FNDC and TRAION contributed $2,115 and $2,720 (excluding GST) respectively, towards project costs such as room and equipment hire and catering.

FNDC have also contributed funding from their Significant Natural Areas Fund towards fencing and planting costs associated with the project. This was a total of $20,000 which was split between five different restoration projects in the catchment (T. Te Haara, FNDC, pers. comm.).

One of the larger properties in the Lake Ōmāpere catchment received funding from NgaWhenuaRahui to fence the lake margin and a large bush area (outside of the lake catchment). NgaWhenuaRahui is a contestable fund to facilitate the voluntary protection of indigenous ecosystems on Maori owned land while honouring the rights guaranteed to Maori landowners under the Treaty of Waitangi. The fund, administered by the NgaWhenuaRahui committee and serviced by the Department of Conservation, receives an annual allocation of funds from Government.

The contract for the property in the catchment was finalised in 2006. Fencing was carried out over 2006/2007 and includes an eight wire post and batten fences and at least a 20 metre wide riparian margin (M. Carter, NgaWhenuaRahui, pers. comm.). Unlike most other funds, NgaWhenuaRahui can cover up to 100% of the costs. From 2006 to 2011 a total of $252,666 has been funded, however, this includes the 60 ha bush outside the catchment. In the catchment, thisfunding has covered 7 kilometres of fencing on the lake margin, restoration planting over two years, alternative stock water supply and pest control.Associated with the funding is a legal agreement to protect the land. In the case of the area protected in the Lake Ōmāpere catchment it isaNgaWhenuaRahuiKawenata under s77A of the Reserves Act 1977 of approximately 30 ha. Within this covenanted area are some of the wetlands that contain Northland mudfish populations.

SMF funding

The SMF funding used for the project was a total of $114,869 (excluding GST). The majority of this funding was used to cover the cost of research by NIWA ($39,500), other dive surveys ($4,700) andtime spent on project work by the four Lake Ōmāpere Trustees and their advisor on LOPMG ($47,600). The remainder was project overheads such as travel expenses, Hui and public meeting costs, printing and advertising costs. Note the SMF funding is includedin theamount spent on Lake Ōmāpere by the NRC.

Current state and trends for the lake and its catchment

Lake water quality

There is reasonably regular water quality data for the two sampling locations on the lake from 1992 to present. Sampling frequency has fluctuated over the last six years, from 5 occasions in 2009 to 10 in 2006 (average of 7 per year). This section presentscurrent water quality in the lake and trends for the last 10 and 20 years. But as the lake has switched between a macrophyte-dominated clear water state and a turbid algal-dominated (de-vegetated) state over the last 25 years, it is important to compare changes in water quality over time taking these switches into account (NRC 2006, Champion and Burns 2001).

Current state

Lake Ōmāpere remains in an enriched and turbid state. The lake has been sampled on eight occasions between October 2010 and September 2011 inclusive. The average Trophic Level Index (TLI) score for this periodwas 4.79 for sites 106461 and 106463 combined (table 13 in appendix C). A TLI score of less than five is indicative of a eutrophic lake. The TLI score was above five on 2 of the 7 sampling occasions for site 106461 and on 3 occasions for site 106463. This is a significant improvement on the last 10 years (Figure 4), however, the lake has improved to a eutrophic state previously in 1992 to 1995 (Figure5, also refer to pg 85 of Burns et al. 2000).

Ten year trends

The lake deteriorated to a hypertrophic state in 2002 when the weed collapsed leading to algal blooms. The lake remained predominately hypertrophic (with seasonal variation) for about five years (Figure 4).

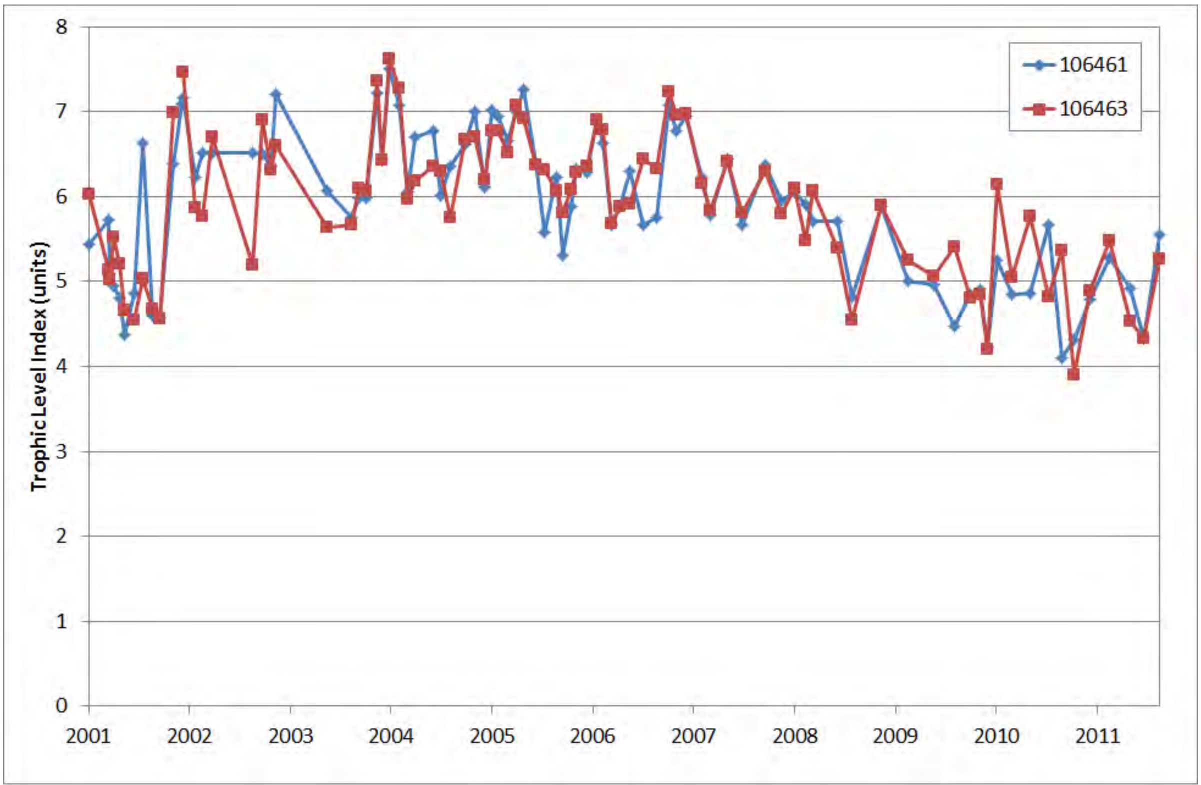

Figure 4:Trophic level index from February 2001 to September 2011 at the two 25% depth sites (106461 and 106463) sampled in Lake Ōmāpere

Since 2007 it has steadily improved from hypertrophic to supertrophic and in the last year has been predominately eutrophic. These changes are supported by trend analysis on data from 2002 to 2011 that indicates that water quality has improved in Lake Ōmāpere over the last 10 years (NRC unpublished).Significant improvementswere found for chlorophyll a, clarity, total nitrogen, trophic level index and suspended solids. Clarity increased by 5 cm per year at site 106461 and 3 cm per year at site 106463. Chlorophyll a decreased by 9.21 and 8.09 mg/L per year,at sites 106461 and 106463 respectively. Total nitrogen decreased by 274 and 219mg/L per year at sites 106461 and 106463 respectively. In turn, TLI decreased by 0.19 and 0.15 units per year at 106461 and 106463 respectively.

In a recent report commissioned by the Ministry for the Environment, of 18 lakes nationally that had sufficient data to analyse trends for 10 years (2000 to 2009), Lake Ōmāpere was the only lake that showed an improvement in TLI by decreasing by 2% per year (Verburg et al. 2010). Of the 68 lakes analysed for the 2005 to 2009 period, 8 showed an improvement in TLI, one of which was Lake Ōmāpere with a decrease in TLI of 7.4% per year.

Nineteen year trends

When you look at the 19 oddyears data for the lake you can clearly see the switches between the two states (For example, Figures 5 and 7). Clarity improved in 1993 to the point where the *E. densa* started to grow back in 1994 (Ray at al. 2006). The *E. densa* quickly grew to cover the whole lake, until the lake started to collapse in 2001/2002.

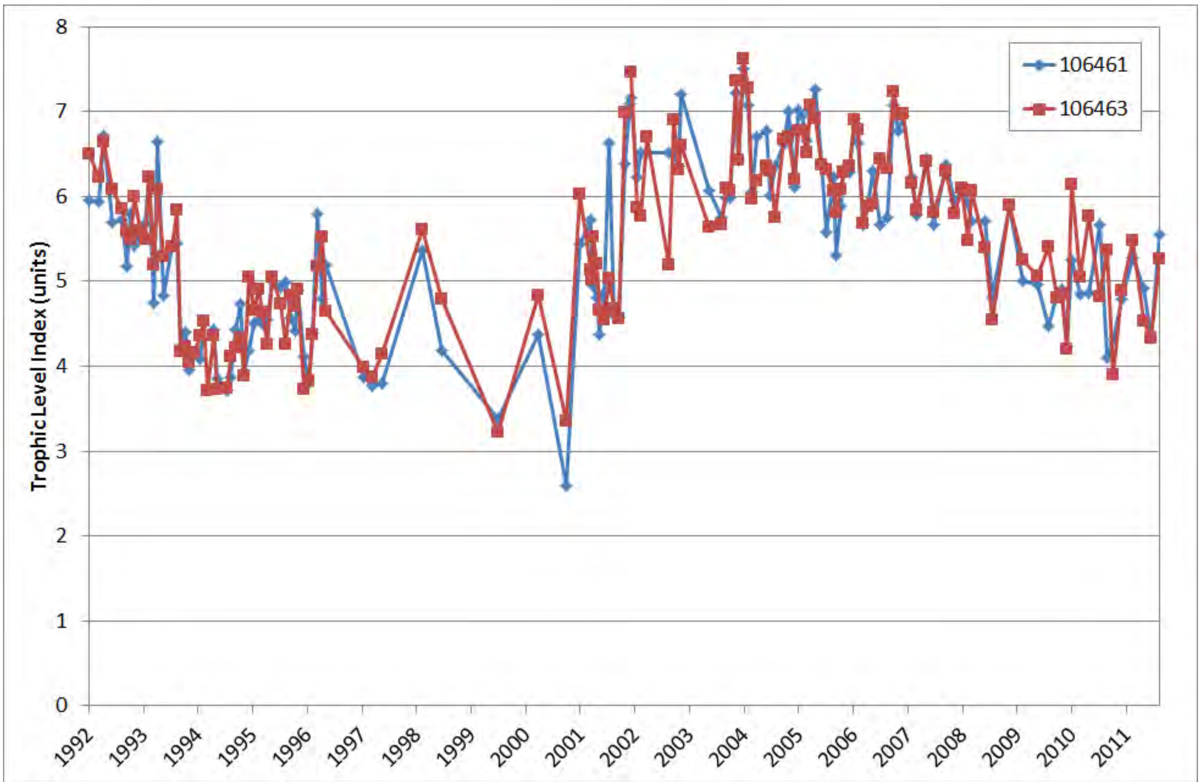

Figure 5:Trophic level index from February 1992 to September 2011 at the two 25% depth sites (106461 and 106463) sampled in Lake Ōmāpere

Trend analysison datafrom February 1992 to September 2011, ignoring the switching state of the lake, shows different trends to the 10 year period. TP, TN, SS and TLI all increased significantly over the 19 years for at least one site in the lake (Table 14 in Appendix C) and all of these trends, except for TLI, were environmentally meaningful (ie, change per year >1% of the median). However, if the trend analysis is repeated for the same period but with the period when the lake was in a clear water state (January 1994 to November 2001) removed from the analysis the trends are more similar to the 10 year period, ie, improving (Table 15 in Appendix C).There was a significant and environmentally meaningful improving trend for SS, VSS, TN and water clarity at both 106461 and 106463. There was also significant improving trends for TLI at both sites (Figure 6) but the change per year was only at least 1% of the median (environmentally meaningful) at site 106461. The trends for TP were not significant at the 5% level.

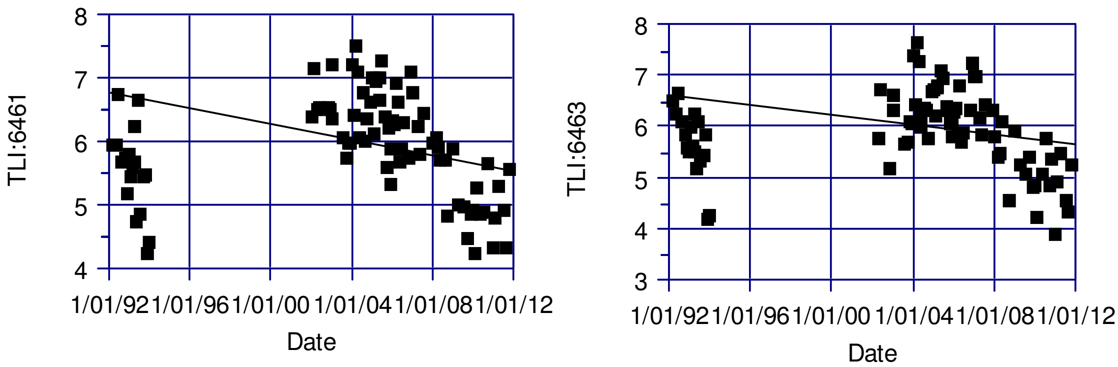

Figure 6: TLI for sites 106461 (left) and 106463 (right) from February 1992 to September 2011 with the clear water phase of the lake removed (January 1994 to November 2011). Line shown on graph is Sen Slope from Mann Kendall Trend test(Table 15 in Appendix C).

Algal community

Chlorophyll a, an indicator of algal biomass, has been monitored since 1992. Blue green algae (cyanobacteria) testing started in December 2003 and includes cell counts for blue green species and ranked abundance of usually at least the five most common algae species (including non-cyanobacteria). The ranked abundance gives us some information towards community composition by showing which species are dominating the algal community.These show that the algal communityin Lake Ōmāpere has changed substantially over the last two decades.

Algal biomass

Not surprisingly, chlorophyll a shows a similar pattern over the last 19 years to the other water quality measures (discussed above). Chlorophyll a gradually improved from February 1992 to mid-2003 and remained relatively low until late 2000 with one large peak in March 1998 (Figure 7). It remained high with seasonal fluctuations until mid-2007.

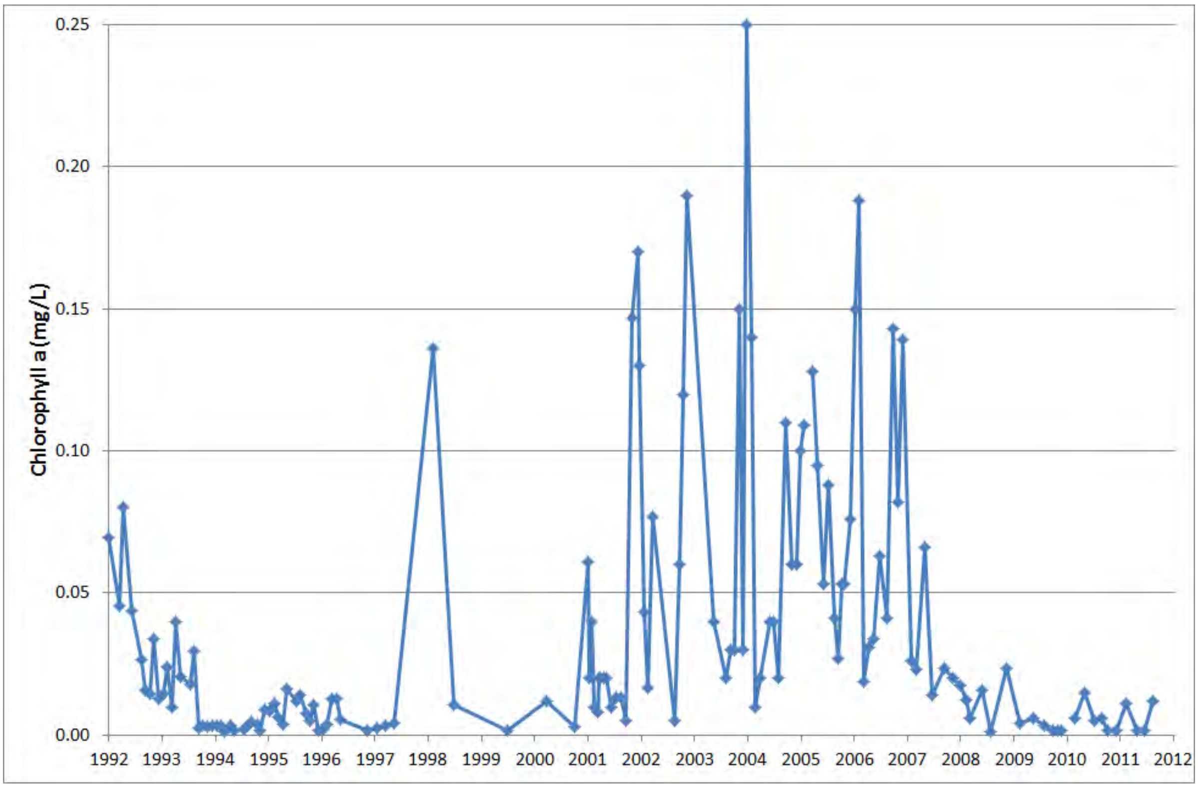

Figure 7:Chlorophyll a levels (mg/L) at Lake Ōmāpere site 106463 from February1992 to September 2011. Note year labels mark February of each year.

Low chlorophyll a levels correspond well with the sampling dates where comments were made in the cyanobacteria testing results that there was “low algal biomass” overall. Seven such comments have been made in the last two years.

Blue green algae

Cyanobacteria cell counts significantly reduced between January 2004 (when cell counting started) and September 2011 ($p < 0.00001$, 75% decrease compared to median per year, Table 14 in Appendix C). There was a dramatic drop in November2006 (Figure 8).Note this is slightly earlier than when the overall algal biomass dropped, showing that the algal bloom continued into 2007 but was no longer dominated by blue green species. This is consistent with a comment made in the cyanobacteria results in November 2006 that there was a “large bloom of green algae”. Cell counts have remained low since November 2006, except for the occasional elevated count in summer months.

The cyanobacteria cell counts correlate well with the ranked abundances (Table 16 in Appendix D). For example, November 2006 is when the most dominant species moved from a blue green to green species (discussed further below). Since 2006 when cell counts have peaked in summer months (eg, February, April and December 2008, March and April 2011), blue green species appear in the five most abundant taxa.

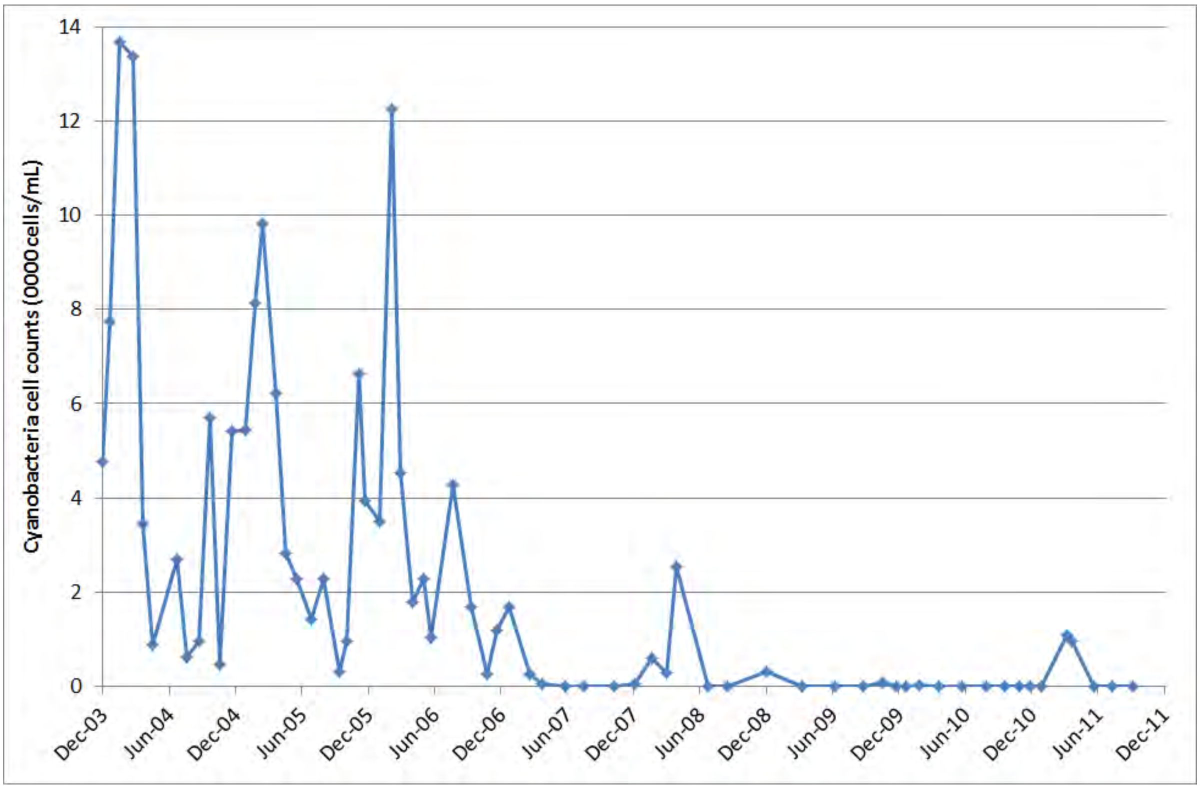

Figure 8: Blue green algae cell counts for samples collected from the surface at site 106463 in Lake Ōmāpere from December 2003 to September 2011

Community composition

The community composition has clearly changed since December 2003 when algae identification was started (Appendix D). The most common algae was typically a blue green species from December 2003 to September 2006 inclusive and often also the second most abundant species was also a blue green. In November 2006 the most abundant was green algae species up to mid 2007, however, blue green algae were still in the top five most abundant species. From October 2007 the most dominant algae was diatoms for about a year and blue greens rarely featured in the five most abundant taxa. Since late 2008 the most common algae has varied but has rarely been blue green species, and only ever in summer months.

Nutrient limitation

The TN:TP ratio for the lake varies substantially over time (figure 9), suggesting that there is no consistent nutrient limitation in the lake. Lakes are sometimes considered to be potentially nitrogen limited if the TN:TP< 7:1 and phosphorus limited if the TN:TP > 15:1 (Ministry for the Environment 2007). As the nutrients are so high in Lake Ōmāpere the majority of the time, algae is more likely to be limited by light. When nutrient levels are low algae is likely to be limited by either nutrient or both at different times.

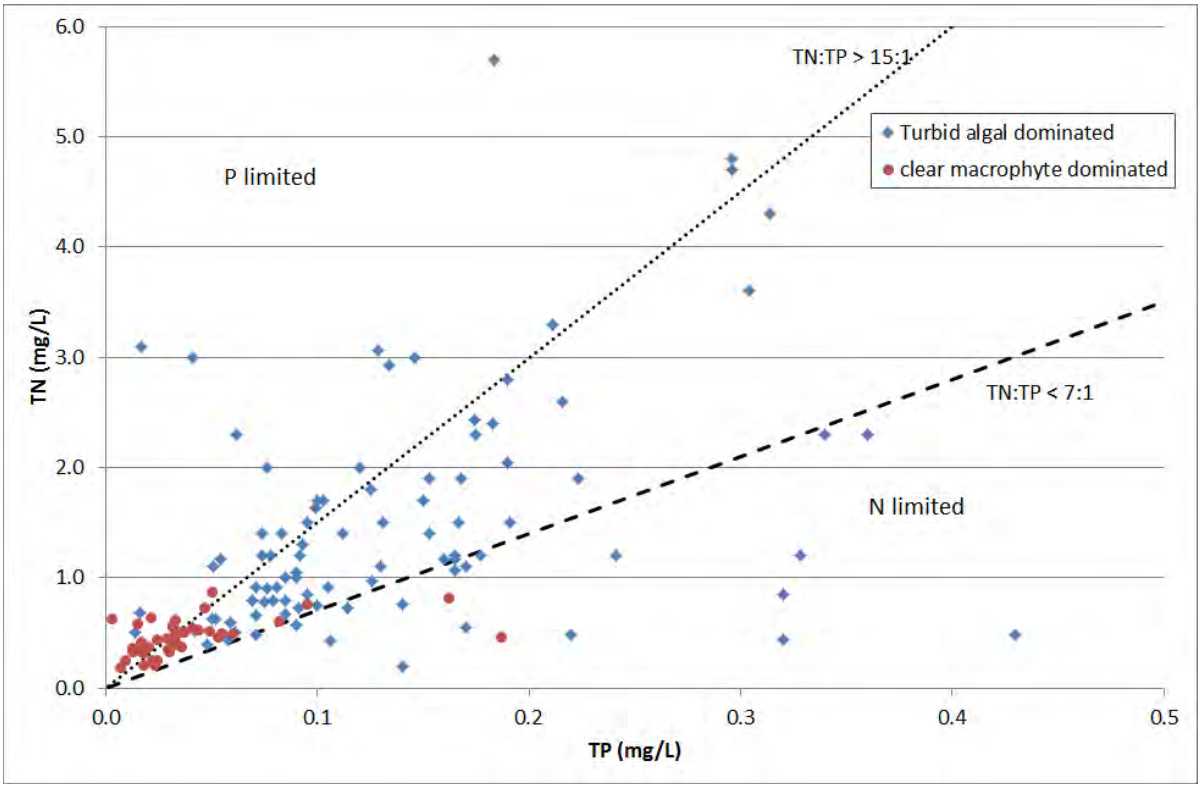

Figure 9: TN versus TP for Lake Ōmāpere (site 106463). TN:TP ratios taken from Ministry for the Environment (2007)

Lake sediments

Lake sediments have been sampled at four sites on four occasions; November 2004, December 2005, October 2007 and October 2010. Although it does appear that levels have decreased for some nutrients at some sites, particularly ammoniacal nitrogen (Figure 10), it is not consistent across all sites and/or nutrients. There is insufficient data to carry out formal trend analysis. Regardless of some sites showing improvements (decreases) in some nutrients, nutrient levels are still relatively high, particularly TN (Figure 11).

There is limited research of nutrient levels in shallow lakes but more for deeper volcanic lakes, however, caution needs to be taken when interpreting these comparisons as nutrient processes vary between lakes depending on many factors, including lake depth and geology. However, the average and maximum nutrient levels in Lake Ōmāpere are in the region of the levels found in other enriched lakes (Table 17 in Appendix E). The maximum TN recorded for Lake Ōmāpere was 5.8 g/Kg (Figure 11). The maximum TN level (in g/Kg) recorded for Lake Okeechobee, a shallow turbid subtropical lake in Florida, was 28; for 12 Te Arawa volcanic lakes was 18.9; for Nelson Lakes (Rotoroa and Rotoiti) 5.4 and 4.0 respectively and for Lake Taupo was 3.3 (Appendix E).

The maximum TP recorded for Lake Ōmāpere was 519 mg/Kg (Figure 12). The maximum TP level (in mg/Kg) recorded for Lake Okeechobee was 958; for 12 Te Arawa volcanic lakes was 3,489; for Nelson Lakes (Rotoroa and Rotoiti) 1,210 and 1,490 respectively and for Lake Taupo was 1,700 (Appendix E).

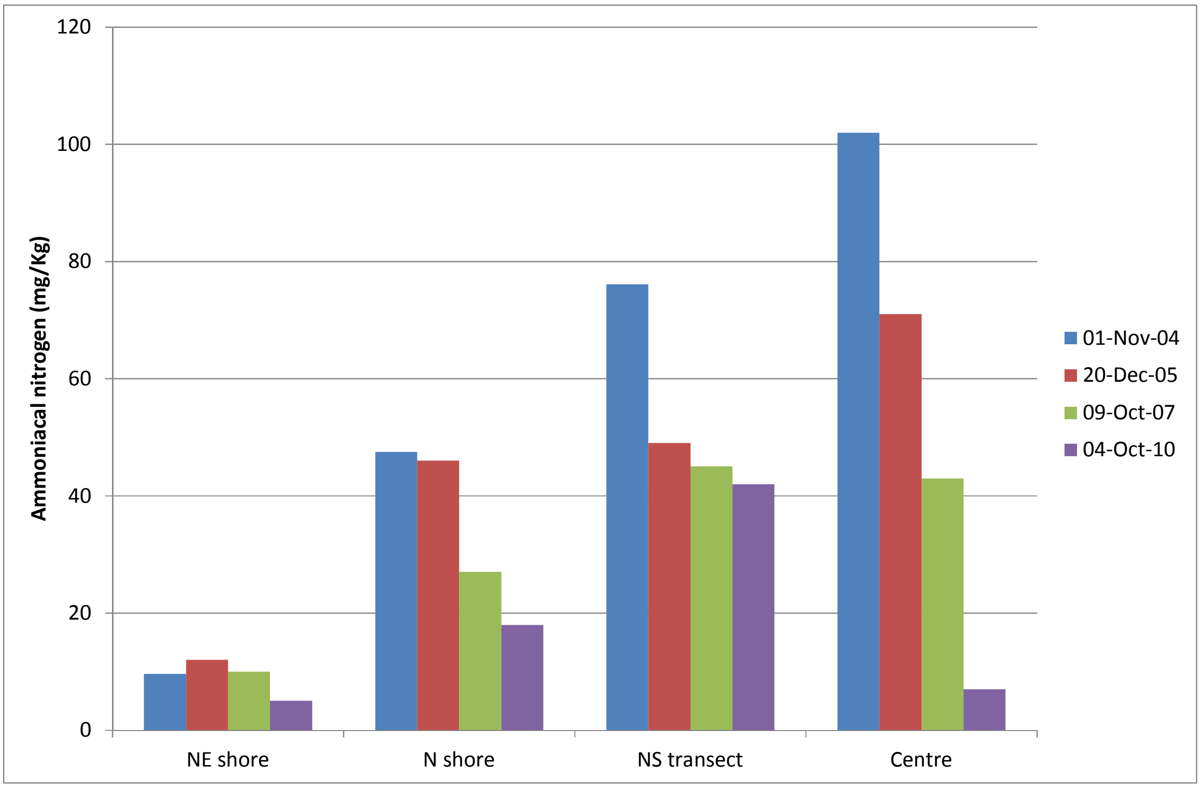

Figure 10: Ammoniacal nitrogen (NH_4) levels (mg/Kg) in sediment samples from four sites in Lake Ōmāpere collected on four occasions. Sites shown from northern most site on left to most southern on right.

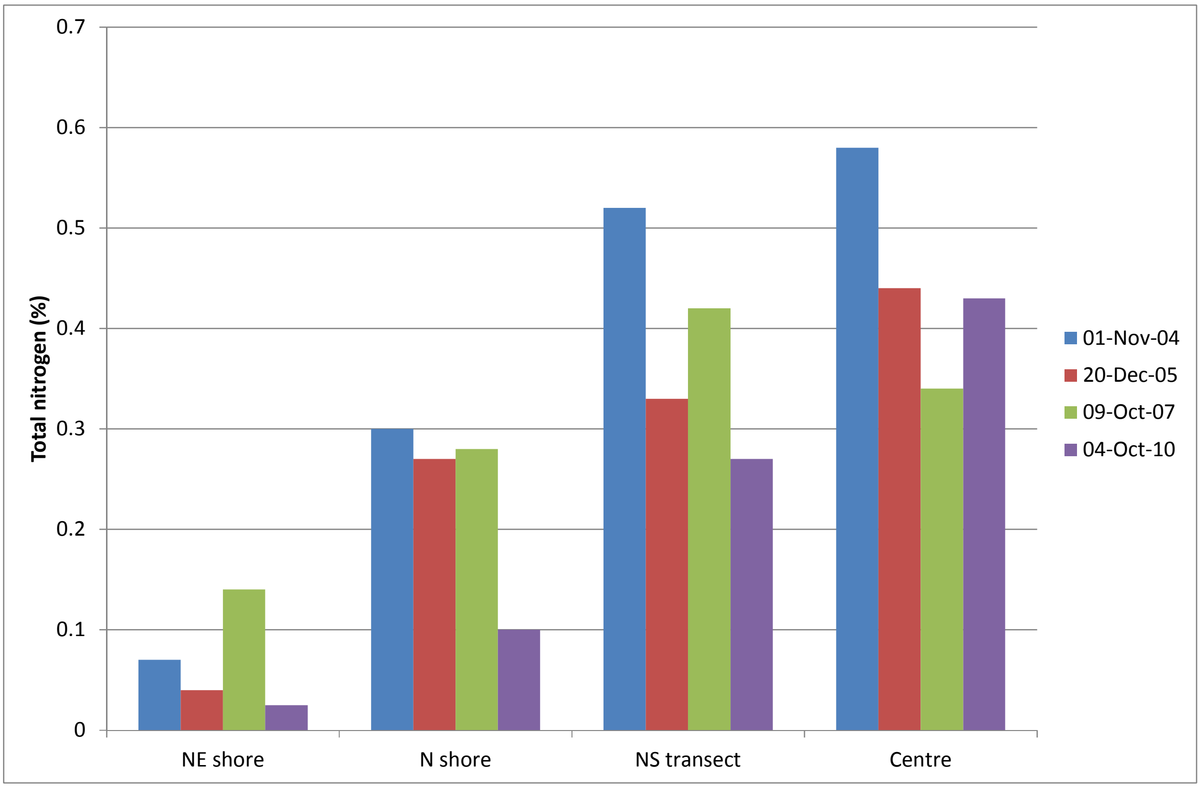

Figure 11: Total nitrogen (TN) levels (%) in sediment samples from four sites in Lake Ōmāpere collected on four occasions. Sites shown from northern most site on left to most southern on right.

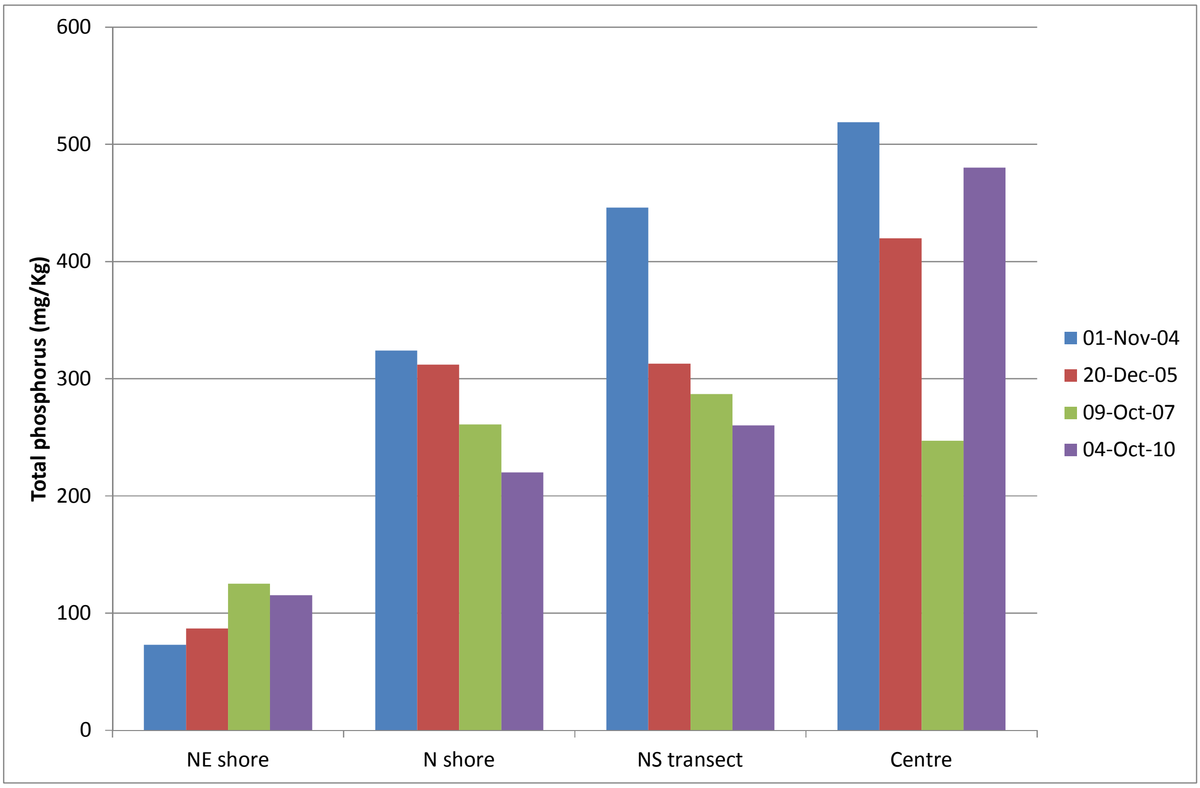

Figure 12: Total phosphorus (TP) levels (mg/Kg) in sediment samples from four sites in Lake Ōmāpere collected on four occasions. Sites shown from northern most site on left to most southern on right.

The results also show that the variation in sediment nutrients within the lake is high, with the site at the north eastern shore consistently having the lowest nutrient levels and the most southern site near the centre of the lake usually having the highest. The sediment at the two most northern sites (NE shore and N shore) was dominated by clay and gravel and had higher water content, than the two sites near the centre of the lake, which were dominated by silt.

Potential nutrient load to lake

The nutrients in the sediment are important to the restoration of the lake as they are a significant internal nutrient source through wind driven sediment re-suspension. For example, based on average TN and TP results for sediment samples (Table 17 in appendix E) there is in the region of 500 tonnes of TN and 50 tonnes of TP in the top 2 cm of sediment in the lake bed. However, the amount of this that is biologically available will be much less. In comparison, based on the last three years average, there isan estimated 11.8 tonnes of TN and 2.6 tonnes of TP in the water column of the lake.

Catchment water quality

NRC has sampled seven different streams and farm drains (nine sites) flowing into the Lake on an adhoc basis since August 2005. This includes Parakataio Stream, the largest stream in the catchment, which has been sampled on 10 occasions. There is a small amount of water quality data from storm event sampling of Parakataio Stream from 1995/1996. Also NIWA sampled approximately 20 surface water flows into Lake Ōmāpere, including Parakataio Stream, in May 2006 as part of the groundwater survey (Gibbs and MacKay 2006).

Nutrient levels in most of these streams and drains have been exceptionally high on occasion (Table 18 in Appendix F). For example, TN exceeded 725 mg/m^3(theoretical cut-off between a eutrophic and supertrophic lake)on 7 of 10 sampling occasionsinParakataio Stream at site 108387. The average TN in the lake for samples between October 2008 and September 2011 was 586 mg/m^3. The levels in Parakataio Stream were above this on all 10 occasions. Likewise for a drain on the north eastern side of the lake (site 108683), that has been sampled on five occasions. Four of the five results are higher than the average TN in the lake.

These samples have typically been collected under base flows (ie, not after heavy rain) and therefore as would be expected suspended solids have been low on all occasions when tested (all results < 30 g/m^3).Total phosphorus levels have also been relatively low on the majority of occasions. Average TP in the lake for samples between October 2008 and September 2011 was 134 mg/m^3. Only 1 of the 10 results for Parakataio Stream (site 108387) is above this and likewise only one result is above the theoretical cut off for a eutrophic lake of 43 mg/m^3.

High flow events

However, both TP and SS inputs are more closely related to rainfall events than TN. NIWA was commissioned by NRC to carry out storm event sampling from Parakataio Stream betweenJune 1995 and June 1996 (NRC 1996). These results showed that suspended solids (mostly sediment) was highest during the early part of a flood event. The highest suspended solids result was617 g/m^3 and there were at least 10 high flow events (of 14 events) where suspended solids exceeded 100 g/m^3 in the year of sampling(Table 19 in Appendix F).The highest TP result was 1,990mg/m^3 and all 9 high flow events that had a result, had TP levels above 500 mg/m^3.

However, nitrogen was less influenced by heavy rain. NNN levels recorded in base flow conditions since 2005 were as high as those recorded during storm events in 1995 and 1996 (Table 18 and 19 in appendix F). The fact that many of the streams and drains carry high nitrogen loads for the majority of the year is most likely because they mainly originate from springs, particularly at the south eastern end of the lake, and are likely to be intercepting shallow groundwater (Gibbs and Mackay 2006).

Nutrient loads to lake

From the available data estimates of the nutrient load to the lake from Parakataio Stream can be calculated, however, they are very rough estimates asboth the flow and water quality data is very limited. Also the base flow nutrient load is based on recent water quality data and 1994 to 1996 flow data, while the high flow nutrient load is based on 1995/1996 water quality and flow data. During base flow conditions the average inputs into the lake from Parakataio Stream are in the region of 80 g of NNN/hour and 2 g of TP/hour (see Appendix F for calculations). However, during high flow events the average inputs into the lake are in the region of 1 to 1.5Kg of NNN/hour and 3 to 4Kg of TP/hour.

Surface water results from groundwater survey

As part of the groundwater survey in May 2006, NIWA sampled approximately 20 surface water flows into Lake Ōmāpere and analysed them for DRP, $NH_4$and NNN (Gibbs and MacKay 2006). They found ten of the surface inflows to have high NNN levels, much higher than the groundwater inflows, four surface inflows to have elevated DRP levels and only one had elevatedNH_4 levels.

They suggest that these surface inflows are intercepting the nitrogen-enriched groundwater further back in the catchment and carrying it directly to the lake, by-passing the nutrient uptake of marginal plants that is likely to be occurring with the groundwater (see below). They also suggest the few high DRP levels could be a result of recent superphosphate fertiliser application.

Trends over time

There is insufficient data to carry out formal trend analysis for the catchment streams, however, looking at the available data for Parakataio Stream there does not appear to be any signs of a trend (either improving or deteriorating)for the last six years (Figure 13). However, given the extremely low number of samples (10) this is inconclusive. Either way the results from Parakataio Stream and other waterways show that they are still contributing high nutrient levels to the lake.

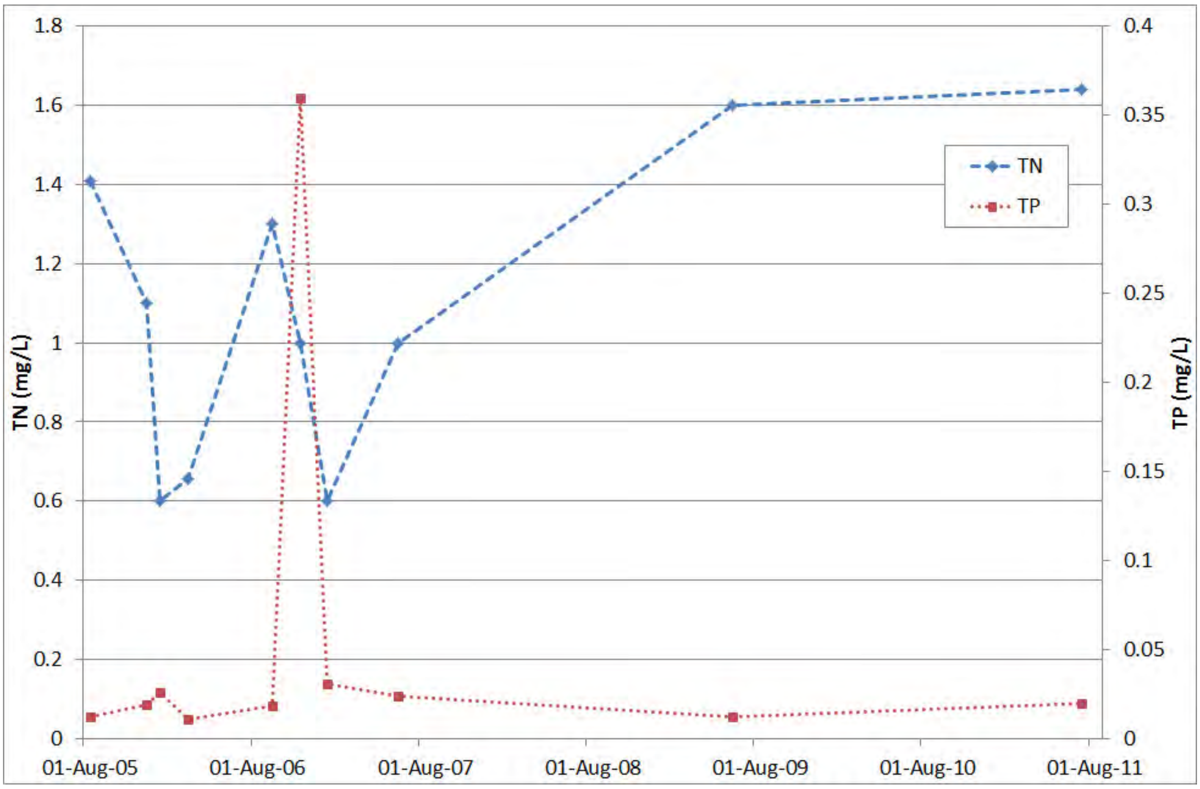

Figure 13: TN and TP results for Parakataio Stream (site 108387). Note lines are dotted to highlight these are discrete andirregular sampling points and that there is a low number of data points.

Groundwater quality

As part of the groundwater survey in May 2006, NIWA sampled approximately 18 groundwater flows into Lake Ōmāpere and analysed them for DRP, $NH_4$and NNN (Gibbs and MacKay 2006).They found groundwater was difficult to obtain due to the nature of the soil around the lake margin, with 68% of attempted locations being unable to be sampled for groundwater. Fine clays and impermeable rock appeared to block groundwater flow into the lake and resulted in surface flows being the main land drainage mechanism.However, some areas did have highly permeable sandy sediments, which may conduct considerable amounts of groundwater.

All NNN levels were below 0.07 mg/L and all DRP levels were below 0.03 mg/L except one site at the northern shore had 0.149 mg/L. NH_4 levels were mostly below 0.09 mg/L, except two sites at the northern shore and one at the southern shore. The low dissolved inorganic nitrogen (DIN = NNN + NH_4) may be explained by the high plant uptake rates by marginal wetlands and kikuyu grass and microbial nitrification-denitrification processes transforming DIN to nitrogen gas (Gibbs and Mackay 2006).

Although it was a one-off survey they consider the groundwater nutrient levels to be representative of levels for most of the year where marginal vegetation was growing. They concluded that the shallow groundwater is contributing little nutrients to the lake, as the majority of it is entering the lake as surface flows and where groundwater is entering the lake, the nutrient levels are low.

Lake ecological condition

There is limited data on the ecological condition of the Lake, most likely due to the poor condition it has been in since oxygen weed was introduced. NIWA last surveyed the lake as part of Northlands ecological monitoring programme in 2005 (Wells and Champion 2010). The lakes in Northland are prioritised for ecological value based on indigenous biota, endangered species and habitat availability. Based on the 2005 survey Lake Ōmāpere was assigned an overall ranking of low, as it was de-vegetated. However, the report notes that wetlands on the lake margins contain the endangered Northland mudfish.

Wildland Consultants (2011) recently ranked255 Northland freshwater wetlands based on eight weighted criteria:

- wetland area
- size contribution to wetlands within ecological district
- Land Environments of New Zealand threat category
- wetland quality and rarity (representativeness)
- vegetation diversity and patterns
- hydrological integrity and water quality
- threatened, at risk and regionally significant species
- dominance of indigenous plants in the upper-most vegetation layer.

Lake Ōmāpere and Environs was ranked 11th equal, with an overall score of 77.64 out of 100.Lake Ōmāpere and Environs has a high score because of the range of wetland and vegetation types present. As well as the Lake, there arepeat bogs, swamp forests, rushlands and flaxlands on the lake margins and the lakeside turf plants. The lake and surrounding catchment provides habitat for 10 regionally significant plant species, 5 at risk species and 4 threatened species. The nationally critical *Isoeteskirkii* is only known to be from this Lake. Lake Ōmāpere and Environs is ranked top of the lake (lacustrine) wetlands and ranked second for the Kaikohe Ecological District.

Freshwater mussels

Hyridellamenziesi or torewai are an important part of the lake ecosystem as they filter feed on algae. An estimated density of 35 mussels/m^2 would be able to filter the entire water column in a day (LOPMG 2005a).

Mussel numbers

In October 2010, the average mussel density in Lake Ōmāpere was 19 mussels/m^2 based on 22 sampling locations. However, their distribution is extremely patchy (see below) with no mussels found in some areas and a maximum density of 72 mussels/m^{2}recorded. Previously maximum densities in Lake Ōmāpereof 126 and 166 mussels/m^2 have been recorded (LOPMG 2006; Champion 2004). The average and maximum mussel densities recorded for Lake Ōmāpere tend to be much greater than what has been published for other New Zealand lakes and rivers (LOPMG 2005a).

Change in numbers

There was high mortality rates of mussels following the collapse of the *E. densa* beds in both 1985 and 2001, most likely as a result of low oxygen levels on the lake bed (LOPMG 2005a). In April 2001, average mussel densities were recorded as 4 living mussels/m^2 (figure 14) with 30 dead mussels/m^2. However, by April 2004 the mussel population had recovered to the pre-collapse densities and has stayed reasonably stable since. The apparent drop in densities after April 2004 is more likely to be related to sampling location differences and number of locations sampled by NIWA compared to NRC, rather than a drop in mussel numbers. Likewise the slight increase in December 2005 is likely to be a reflection of the mussel's patchy distribution.

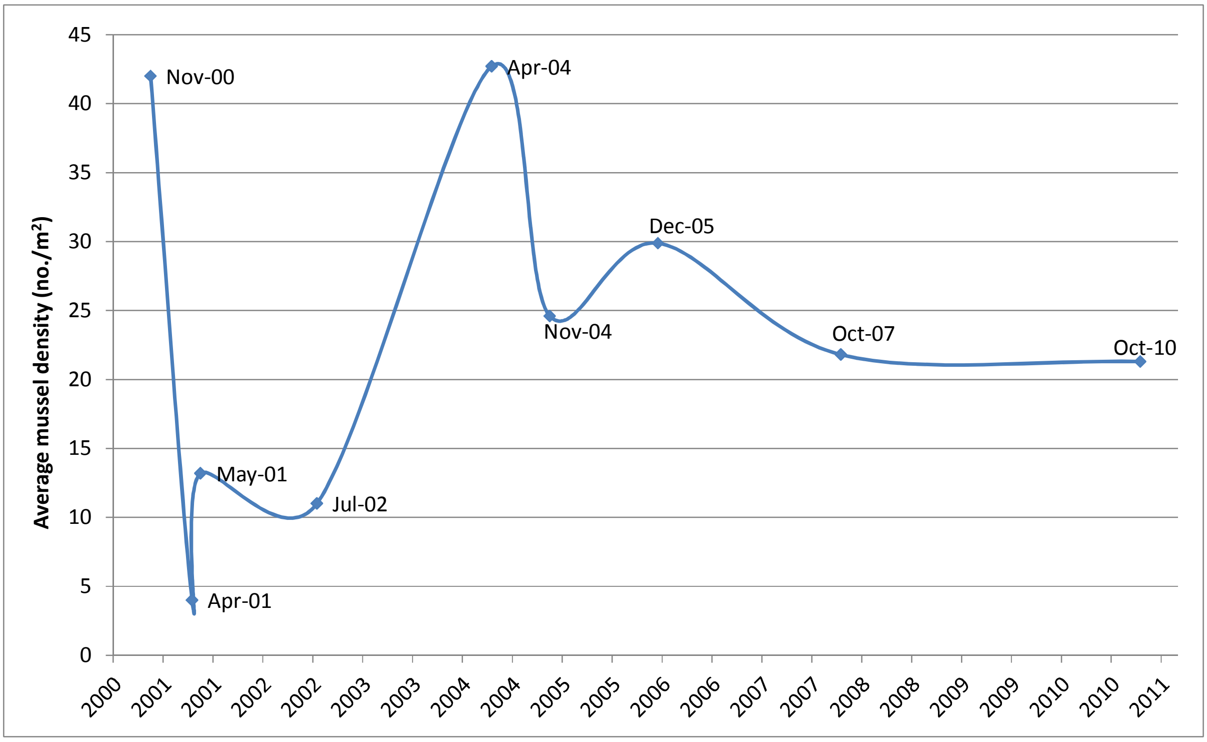

Figure 14: Average mussel density in Lake Ōmāpere based on survey data

Mussel distribution

The mussels have an extremely patchy distribution (figure 15), which isdue to the many factors that can affect mussel densities and distribution (LOPMG 2005a). In October 2010, similar to previous surveys, high mussel numbers were found at the northern end of the lake with an average of 29 mussels/m^2 and fewer in the centre and southern end of the lake with an average of 8 mussels/m^2. It is likely that mussels densities are higher in other areas of the lake, particularly close to the shore. During a dive check for weeds in November 2011, mussel coverage was estimated to be 20 to 40% at the southern end of the lake (L. Forrester, NRC, pers. comm.).

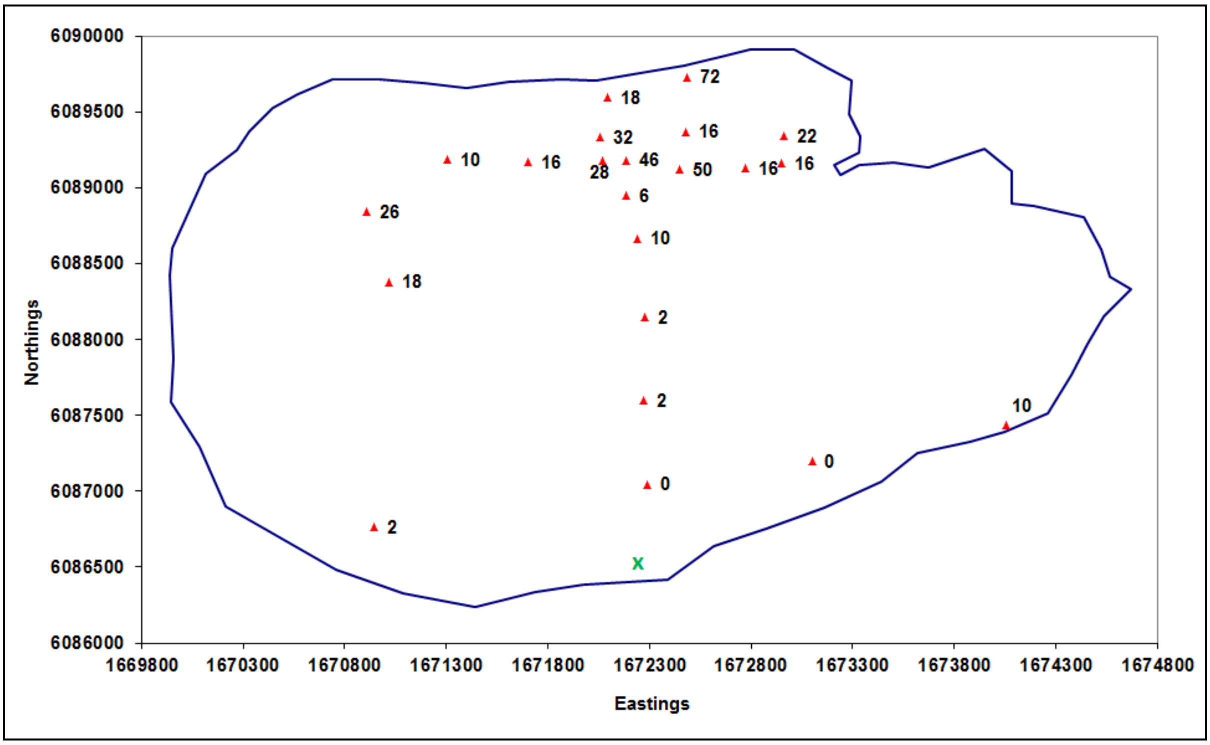

Figure 15: Mussel density (number/m^2) in October 2010 at each sampling location in Lake Ōmāpere. The green x marks approximate location in November 2011 where coverage was estimated to be 20 – 40%.

Mussel sizes

Although the mussel numbers in Lake Ōmāpere are high and stable, there was concern that the mussel sizes were showing a slight shift in the population towards larger and therefore older mussels (LOPMG 2006). However, the 2010 survey results show the size distribution of the surveyed population to be similar to 2004 (figure 16).

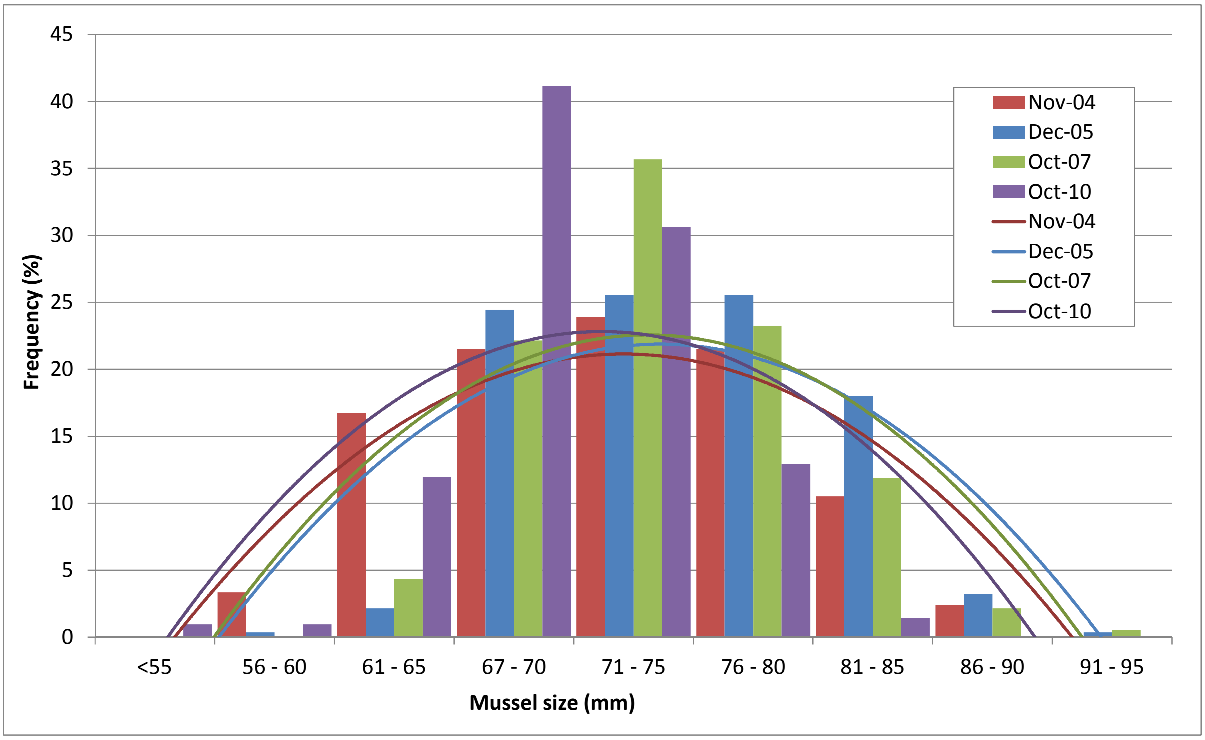

Figure 16: Percentage of the mussel population sampled that falls into each size class for four surveys

During the October 2010 survey one mussel between 45 and 50 mm and one between 50 and 55 mm were found.

Other indigenous biodiversity

Other aquatic invertebrates

Other than the mussel surveys, there has been limited surveys of invertebrates in the lake. A 1995 survey found freshwater mussels, two snails (*Potamopyrgusantipodarum*and *Austropepleatomentosa*), moth larvae (*Hygraulanitens*), planarians (flatworms), bryozoans and chironomids. Odonata (dragonfly/damselfly larvae) and sponges have also been recorded (Champion and Burns 2001). Koura (*Paranephropsplanifrons*) have also been recorded in the lake (Wells and Champion 2010). No koura were found in the lake in the 2011 fish survey (M. McGlynn, pers. comm.) but they have been found recently by the eel fisherman(LOPMG 2005a) and during fish surveys in 2007 and 2008 (NZFFD).

Fish

There is four native fish recorded from the lake and catchment, long fin and short fin eels (tuna), the nationally endangered Northland mudfish and smelt (Table 9). Smelt have not been recorded in the lake since a survey by DOC in 1997, at which time they were abundant. There has been none found in the five most recent fish surveys in the lake in 2005, 2007, 2008, 2009 and 2011. Champion and Burns (2001) list common bully as being in the lake. However, there are no records of common bully on the NZFFD and none have been found in the five recent fish surveys.

Table 9: Native fish recorded in the lake and/or its catchment (NZFFD, Champion and Burns 2001, LOPMG 2005a, McGlynn 2009)

Common name	Recorded in	Location(s)	Range in number of fish recorded
Long fin eel	1988, 1997, 2007, 2008, 2011	Lake, unnamed trib, Parakataio Stream	1 – 12
Short fin eel	1965, 1988, 1997, 2000, 2005, 2007, 2008, 2009, 2011	Lake, unnamed trib, unnamed wetland, Parakataio Stream	1 – 300
Northland mudfish	2000, 2001, 2003, 2007, 2009, 2010	Lake, unnamed trib, unnamed wetlands	1 – 408
Smelt	1965, 1966, 1988, 1997	Lake	4 – 20

Native aquatic plants

Emergent vegetation, including dense bands (> 75% cover) of raupō (*Typhaorientalis*),kuta (*Schoenoplectustabernaemontani*) and jointed twig rush (*Machaerinaarticulata*),to depths of 1.2 and 1.3 metres was found on the western shore in 2005 (Wells and Champion 2010).

During the June 2005 survey, the submerged macrophytes; *Potamogetonochreatus* and *Charaaustralis* were found throughout the lake and the turf plants; *Nitellastuartii*, *Glossostigmaelatinoides, Glossostigmacleistanthum* and*Elatinegratoiloides* were found in the shallow margins. Although not found in 2005, historically, the low growing *Lilaeopsis novae-zelandiae*, the water milfoil *Myriophyllumpropinquum* and the acutely endangered *Isoeteskirkii*have been found in the lake (Champion et al. 2002).The genetically distinct*Isoeteskirkii* var. *flabellata*, which was last recorded in the lake in 1998, may now be extinct in the wild (Wells and Champion 2010). Plants were cultivated from seeds collected from Lake Ōmāpere in 1998 and are held at NIWA.

No *Isoetes* plants germinated from sediment cores taken from Lake Ōmāpere in 2004 in the germination experiments carried out by NIWA (Champion 2005). However, four native plants did germinate from the experiments: the charophyte*Charaaustralis*and the turf plants;*Nitella*, *Glossostigmacleistanthum*, *Elatinegratoiloides.* Based on this,estimates of the number of viable seeds (per m^2)are 26 *C. australis*in the lake centre and 44 *C. australis* and 53 turf plants in the shallows (north and south).

In 2001, the only submerged plant found in the lake was the invasive exotic plant *Egeriadensa*(Champion et al. 2002) and very few submerged plants have been recorded since. The only submerged plants that have been recorded in the lake since 2002 are turf plants. Surveys in 2006 on the eastern shores of the lake recorded four turf plants; the regionally rare *Gratiolasexdentata* and *Glossostigmaelatinoides*; the regionally critically rare *Limosellalineata* and the small annual daisy, sneezeweed *Centipeda*sp. (Forester unpublished). One small turf plant *Glossostigma* sp. was found at the southern end of the lake in November 2011 (L. Forester, NRC,pers. comm.). Emergent vegetation, such as kuta and raupo, still exist on the margins, particularly on the more sheltered southern and eastern shores, however, the area has been reduced due to consumption by grass carp (A. Martin, LOT, and P. Champion, NIWA, pers. comm.).

During the plant surveys of the catchment streams and drains in November 2004 and March 2006 only one native aquatic plant was recorded as extensive throughout the catchment, *Potamogetonchessmanii*.

Birds

Only common bird species were recorded during recent Ornithological Society of New Zealand surveys. However, previously the nationally rare bittern (*Botauruapoiciloptilus*) and regionally significant fernbird (*Bowdleria punctate vealeae*) have been recorded from the lake (Wells and Champion 2010). Otherwise there has been a diversity of birdlife recorded on and around the lake historically (LOPMG 2005a).

Black swan (*Cygnus atratus*) numbers have fluctuated with oxygen weed biomass in the past, reaching an estimated 8,000. However, numbers are relatively low at present (E. Simpson, NRC,pers. comm.).

Riparian plants

As discussed above under lake ecological condition, Lake Ōmāpere and Environs is ranked highly because of the range of wetland and vegetation types present. This includes totara bush, peat bogs and shrublands, kahikatea swamp forests, rushlands and flaxlands.

There is a sizable totara bush at the northern end of the lake and also at Mawe Pa on the eastern shore. Surveys in 2006 found both these sites include a large range of native trees and sub-canopy plants (Forester unpublished). However, at both locations thick mats of wandering jew are stopping any native regeneration. A notable find was one plant of poroporo (*Solanum aviculare*) at Mawe Pa. This shrub, in the tomato/potato family, is rare in Northland and would be worth propagating to replant at Lake Ōmāpere on fertile sites.

A stand of tall kahikatea (*Dacrycarpusdacrydioides*) of less than 2ha occurs on the south eastern side of the lake. Again in 2006, a range of trees and canopy species were recorded here and with abouttwo thirds of this area fenced, there was vigorous regeneration of a mix of species (Forester unpublished). This area is a good seed source for propagating and growing plants for restoration planting.

There are a number of shrublands and peat wetlands on the south side of the lake. They support unique plant communities, which tolerate bog soils. Three areas of treeland run down to the lake, the largest of which is around 10ha. Two groundcover herbs uncommon in Northland were recorded in these treelands in the 2006 survey.Peat wetlands on the north western side of the lake have been extensively drained and are used for stock grazing.

Pest species

Aquatic weeds

There have been two submerged exotic plants recorded in the lake, *Utriculariagibba*and*Egeriadensa*. *U. gibba* was recorded in the eastern basin of the lake in 2000 but has not been seen since (Wells and Champion 2010). *E. densa* was accidentally introduced into the lake in the 1970's, with it covering the whole lake by 1984. The *E. densa* collapsed in 1985.It was first observed in the lake againin October 1994. By 2000/2001 there wassurface reaching beds over the entire lake, with an estimated biomass of over 5000 tonnes in December 2000 (Figure 17). The second collapse of *E. densa* started at the end of 2001. There has been no *E. densa*seen since November 2002 during all monitoring visits by NRC and NIWA (Figure 17).

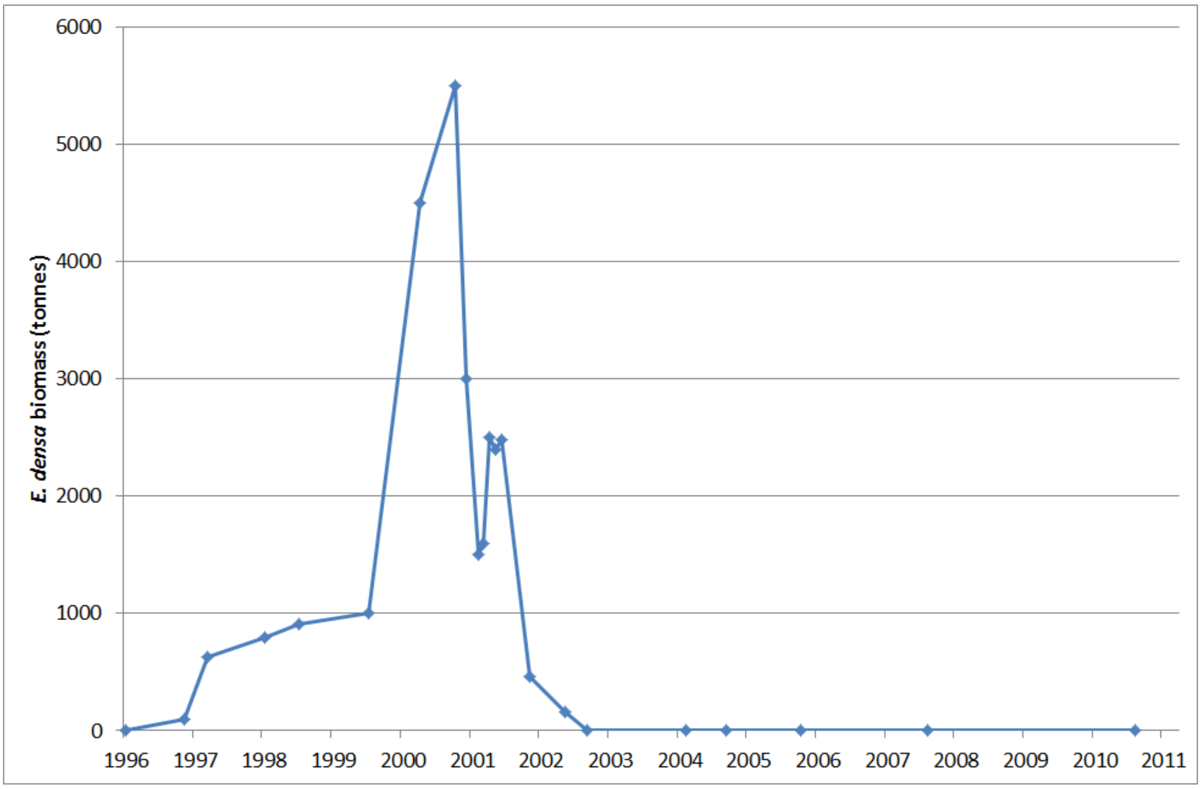

Figure 17: Estimated total *Egeriadensa* biomass (dry weight in tonnes) in Lake Ōmāpere from 1996 to 2011

There has been one emergent pest plant, alligator weed recorded in the lake. It was first recorded in 2005 (Wells and Champion 2010) It is common on the lake edge near the outlet and is thought to have been accidentally introduced on digger equipment used to clear sediment from the outlet area.

During the aquatic plant survey of catchment streams and drains in November 2004 several weeds were found including alligator weed, water celery, water pepper, water cress, water primrose, duckweed and the swamp lily. Of these, two feature in the list of species that threaten Northland lakes, alligator weed and water primrose (table 4.1 of Wells and Champion 2010).

Fish

There have been five different exotic fish recorded in the lake and catchment (Table 10), two of which have been purposefully introduced for management purposes, silver carp and grass carp.During grass carp removal between October 2004 and June 2006, six silver carp were caught. However, there is unlikely to be many (if any) silver carp remaining now, as they were released in 1986, so are nearing the end of their life expectancy. The number of grass carp remaining in the lake is unknown. Numbers were estimated during the project (refer to aquatic weed management in approach taken section) and have been seen in the lake recently (E. Simpson, NRC, pers. comm.).

Up to 2010, mosquito fish had been recorded in the lake on the NZFFD but had not been seen during the many NRC or NIWA monitoring/survey visits (Wells and Champion 2010). But in the most recent fish survey in November 2011, they were found to be widespread throughout the lake (M. McGlynn, pers. comm.).Goldfish are widespread in the lake but are not known as a problematic species in terms of water quality or ecosystem health, like many other coarse fish species,such as rudd, perch, catfish and koi carp. Seventeenbrown bullhead catfish were caught in eel fisherman nets in the lake in 2001 (LOPMG 2005a). All the catfish caught were a similar size, so may have been purposefully introduced. It is possible that there is no catfish remaining in the lake as none have been seen since.

The eel fisherman spent two to three weeks on the lake in April/May 2011 and did not catch or see any grass carp, silver carp or catfish (I. Mitchell, eel contractor, pers. comm.). He also commented that goldfish numbers seemed much lower than usual and he did not see any aquatic plants.

Table 10: Pest fish recorded in the lake and/or its catchment (NZFFD, Champion and Burns 2001, LOPMG 2005a, LOPMG 2006, McGlynn 2009)

Common name	Recorded in	Location	Range in number of fish recorded
Silver carp	1997, 2004, 2005, 2006	Lake	1 – 3
Grass carp	2004, 2008	Lake	3 – 204
Goldfish	1965, 1988, 1997, 2004, 2005, 2007, 2008, 2009	Lake	2 – 284
Catfish	2001	Lake	17
Mosquito fish	2007, 2008, 2011	Lake, unnamed trib.	1 – 20

Riparian plants

There are several weeds mentioned in the completed farm plans that need removing, including wandering jew, gorse and tobacco weed (Hanmore 2008 and 2009). Wandering jew will stop all native regeneration in fenced areas (Forester unpublished, NZLCT unpublished and Hanmore2008 and 2009). Legume plants such as gorse and lupins fix nitrogen from the air and leak nitrates into the groundwater (Gibbs and Mackay 2006). A site visit in 2008 to areas planted in 2006 and 2007 revealed that some plants had not survived due to the lack of weed control in planted areas (NZLCT unpublished). It was noted that kikuyu, convolvulus and willow weed were smothering plants and gorse, blackberry and woolly nightshade had invaded some areas. There is no information on the extent of pest animals in the catchment, other than there was a goat problem in the

NgaWhenuaRahuicovenanted area after fencing. They have since been eradicated (M. Carter, NgaWhenuaRahui, pers. comm.).

Was the project successful?

Could simply say that project was successful if the five project outcomes and tasks within each of these that were required under the SMF contract were completed to the level of quality required within the set timeframes and budget. However, it is not as simple as this. The overall aims of the project were to develop and implement a voluntary lake management strategy that would work towards improving the health of the lake and helping to establish the Lake Ōmāpere trustees in their role as kaitiaki.Also for the project to be successful the work needs to have continued after the project ended.Feedback was sought from key people involved with the project, including Lake Ōmāpere Trustees (3), NRC (5), FNDC, ex-TRAION and ex-DOC staff and landowners and incorporated below. It is worth noting that these are subjective and different people's views may or may not be similar. Where possible this is also discussed.

The five project outcomes

All five project outcomes were completed. Some were fully completed to a high standard within the required timeframe of the SMF contract and contract variations (Table 12 in Appendix B). However, some were only partially completed. For example, training trustees, farmers and community groups to carry out water quality monitoring (task 5.2a) and weed monitoring (task 2.4a) were both limited during the project but included as future actions in the final Strategy. The development of individual farm plans as part of the integrated catchment management component of the project was a huge undertaking and underestimated in terms of land management staff time needed. As a result, tasks 3.2b, 3.2c and 3.3d were not completed during the project and at the time of writing this report had still not been completed. However, all people who have provided feedback on the projecthave all commented that they thought the project was successful because of the amount of action that was done on the ground, in particular fencing and planting.

All project outcomes were completed within the budget for capital costs but the inkind time budgeted for the project was greatly underestimated.

Development of the strategy

The project was successful in terms of the development of the *Restoration and Management Strategy for Lake Ōmāpere*. However, this is only a success if the Strategy is being used and it has not been (see Post project below).

In seeking feedback on the project, one NRC staff member and a Lake Ōmāpere Trustee both commented that the Strategy should have been completed first to identify actions to be carried out and then the actions be done. Rather than the process followed for the project, where many of the actions were completed as part of the project, while the strategy was being developed. They felt that the enthusiasm to do actions on the ground took focus away and slowed the process of developing the strategy. However, the short life span and contract requirements of the funding for the project would have made this difficult. Also many key stakeholders felt that there had been many attempts to improve the lake previously that had been unsuccessful and wanted to see tangible progress on the ground (Table 1).

Improving the health of the lake

Although the health of the lake has improved,there is no evidence,at this stage,that this is due to the project or restoration efforts carried out during or since the project finished.

However, the aim was to**work towards** improving the health of the lake, as goals such as this need to be long term. Therefore, it is too early to determine whether the project and restoration efforts have led to improved lake health (see discussion for more detail).

Establish the trustees in their role as kaitiaki

It is really only the trustees themselves that can comment on this. Of the three trustees that have provided feedback on the project, all of which were involved, they all feel the project assisted the trustees in their role as kaitiakitanga, particularly for those trustees that were actually involved with the project. However, one NRC staff member and one Lake Ōmāpere Trustee commented that they would have liked there to have been more training of trustees during the project, so that they could more easily have continued the work after the project finished.

Other stakeholders that have provided feedback on the project such as NRC and FNDC believe the project did assist the trustees to a certain extent.

Again, the aim was to **work towards** re-establishing the trustees in their role as Kaitiaki. As discussed following the kaitiakitanga research and as part of the strategy development, the project and strategy can only assist the trustees in establishing this role.There are several outputs and outcomes of the project that are tools that could assist the trustees in establishing their role as kaitiaki should they chose to use them, such as the Strategy itself, and the components within this (eg, weed management programme, farm plans), the relationships created and the knowledge gained.

Post-project

For the project to have been successful, action should have continued after the end of the project, the strategy should be being used and updated, and ideally a group similar to LOPMG would still exist to ensure this happens.

Strategy

According to the feedback gained, the Strategy has not been used, reviewed or updated. There are many actions in the Strategy yet to be started (Table 12 in Appendix B), one of which will assist the trustees with training, which has been identified as lacking during the project. However, the LOT has undergone substantial change since the end of the project, including new trustees and a new chairman. Lake Ōmāpere Trustees commented that the Trust is meeting regularly again, is currently deciding on their strategic direction and is closer to being an active Trust again.

Farm plans

Only two landowners have received their farm plan and one of which was only an early draft. There has been no follow up on plans by LOT or NRC. Not surprisingly very little of the recommended works in the farm plans have been done. However, this process did provide substantial information and advice to landowners on best management practice (BMP) and the majority of landowners consulted since the project finished are carrying out BMP in business as usual eg soil testing, applying fertiliser according to their nutrient budget and code of practice. The two landowners who received their farm plan both commented that it did not really provide any new information that they did not already know, particularly in terms of the soils and land use capability components of the plan. When asked, one landowner agreed that the plan was probably information that most farmers would already have a good knowledge of for their property. He also agreed that the table of recommended works and detailed maps are the most useful parts of the plan and probably all that most farmers would need and want.

Riparian management

This is one of the few areas where work has continued. Fencing and planting by Lake Ōmāpere Trustees, landowners and the community has continued since the project finished. However, weed and pest control has been minimal and is particularly important in the first few years following planting to ensure a high survival rate of plants.There are several nurseries still propagating seeds voluntarily for the catchment, however, seed collection has been minimal.One NRC staff member commented that the way the land management component of the project was carried out has meant that many landowners, the trustees and key stakeholders do not have ownership of the work they have done, ie, fencing and planting, and this could be the reason for the lack of weed/pest control. They believe that the land management component of the project, particularly the fencing and planting, should have been more community driven, similar to how landcare groups operate. However, again given the time restraints and requirements under the SMF funding this would have been difficult and it is unlikely that as much would have been achieved in as shorter timeframe without the coordination of key people from NRC, LOT, DOC and other agencies.

Monitoring

Water quality monitoring and weed, mussel and fish surveys have continued since the project finished but in the main have been organised and implemented by NRC with minimal involvement from LOT or key stakeholders.

Discussion

There has been an improvement in lake water quality but there is no evidence, as yet, that the water quality has improved as a result of the project and/or restoration efforts in the catchment. Possible reasons for the improvement in water quality are discussed below but it is unlikely to be due to the project and restoration efforts, because:

- a similar improvement was seen previously in 1993
- there is a large store of nutrients in the lake sediments
- there is still substantial nutrient inputs going in to the lake from catchment streams and drains
- there is no evidence that can directly link improvements in water quality to specific actions
- other projects and research in New Zealand and overseas have shown that it can take many years, even decades, to see improvements following restoration.

These are all discussed further below. There is, however, substantial evidence that the project was successful, for example:

- the majority of SMF project tasks were completed on time within budget
- project outcomes/outputs have provided tools that can assist the trustees in their role as kaitiaki
- all people who have provided feedback on the project have responded that it was successful
- a substantial amount of riparian management has been undertaken and most farmers in the catchment that weren't already doing BMP, have improved their farming practices
- riparian management has led to enhanced indigenous biodiversity in the catchment.

There is no doubt that the project was successful but at a substantial cost both in terms of labour and capital costs and there are still substantial actions yet to be done. This raises the question on whether a different approach may have been more effective ie, would a regulatory approach or the use of more regulatory mechanisms been more effective than the voluntary approach used in terms of cost, time and achievements?

Voluntary versus regulatory

There is no documented evidence that efforts were increased to enforce existing regulations either during the project or post-project. Existing regulations, however, were used to support recommendations to landowners through the farm plan process. There is also file notes that suggest that existing regulations such as the requirement to fence property boundaries may need to be used in some cases to get fencing done. In seeking feedback from people involved with the project, several people commented that regulations may have been useful where landowners were reluctant to fence or be involved in process. One NRC land management staff member commented that the lack of regulations and data to prove effects makes it very difficult to compel farmers to improve land management practices and/or carry out riparian management.

A recent review of regional councils by the Office of the Auditor-General (OAG) suggested that non regulatory approaches are not likely to be sufficient to manage freshwater quality within limits as is required by the National Policy Statement for Freshwater Management (OAG 2011). Some of the councils audited agreed that non-regulatory approaches had not been as effective as they would have liked. A recent literature review by Environmental

Communications Ltd (2010) found that effective and targeted regulation is an essential part of integrated catchment management. However, most people who provided feedback on the project also commented that the voluntary nature of the project was successful and that they didn't think as much would have been achieved on the ground if a regulatory approach had been used instead.

One regulatory approach, that would address some of the aims of the project but not all, is carrying out a plan change to the Regional Water and Soil Plan. The cost and time involved with a plan change varies greatly depending on the size and complexity of and obstruction to the change. To date, the national average timeframe and cost to progress a plan change to operative status is approximately three years at $109,540 per plan change, while the average of three NRC plan changes is approximately four years and $195,000 per plan change (J. Gibbard, NRC, pers. comm.). Depending on the plan change, new rules may need phasing in over a number of years and funding would still be needed to allow for changes to happen on the ground. For example, the rule prohibiting stock in the coastal marine area was given a five year period from when the plan became operative to allow time for fencing, and Environment Fund has been targeted for this fencing. This also still requires advice and information from NRC land management staff.

A regulatory approach is not likely to have achieved the aim to assist the Trustees to establish their role as kaitaki, particularly as some of the issues raised at the first Huiwere a lack of understanding of the regulatory systemand the current system being ineffective (Table 1). Also other components of the project, such as the aquatic weed and water quality monitoring, would still be required if a regulatory approach was used.

Evidence of why improved water quality is unlikely to be due to project

Similar improvement seen previously in 1993

Water quality had improved in the lake to a similar level (ie, eutrophic) by 1993 following the 1985 collapse of *E. densa* and algal blooms. At this point, there was very little riparian management in the catchment and BMP to minimise nutrient run-off to waterways on farms was a relatively new concept with the RMA only being in place two years.

Store of nutrients in lake sediments

There is an estimated 500 tonnes of TN and 50 tonnes of TP in the top 2 cm of lake bed sediments, which is frequently re-suspended into the water column through wind and wave action on the Lake. The amount of this that is biologically available will be much less, however, it is likely to be more than 2 cm of sediment that is re-suspended. The TN and TP in this top layer of sediment is 40 and 20 times greater than the amounts in the water column, respectively. Based on modelling, Verburg et al. (2012) found the phosphorus loading from internal sources in the lake (ie, release from the sediment) was 63% higher than the phosphorus loading from the catchment.

High nutrient inputs from catchment streams and drains

Nutrient levels, particularly nitrogen, were very high on the majority of occasions in many drains and streams sampled at base flow conditions. It is likely that nutrient, particularly phosphorus, and sediment levels will be higher still following rainfall (Gibbs and Mackay 2006), as was shown in historical sampling. The higher nutrient levels and larger water flows following rainfall contribute a substantial nutrient and sediment load to the lake in a short time period. Some of these streams and drains that had high nutrient levels have a reasonable amount of their catchment fenced to exclude stock and with either a grass strip or riparian plantings of trees and flax, for example, Parakataio Stream.

Although there has been substantial riparian management of the lake and catchment this was mostly carried out from late 2005 onwards, less than two years before thelake started to improve. Also the effectiveness of riparian management varies and in most cases should be used in conjunction with other management practices. This is discussed in detail in a recent report reviewing the restoration efforts in the Whaingaroa (Raglan) Harbour catchment (Gray 2011). The most relevant to Lake Ōmāpere is the need for BMP on farms in the catchment and the importance of wetlands and instream plants to assist with instream attenuation of nutrients (ie, reducing the amount of nutrients entering the lake).

No direct evidence

There is no evidence that can link specific actions to improvements in lake or catchment water quality. Unfortunately, this is mostly due to the limited amount of water quality data for the catchment streams and drains (including pre-restoration, post-restoration and during high flows), the lack of a nutrient budget and limited amount of hydrological data. However, none of the people that provided feedback on the project could provide any anecdotal evidence,(eg,visual observations) including eight landowners, and this is often where improvements as a result of restorations efforts are first seen. For example, there is anecdotal evidence of improved health in the Whaingaroa Harbour and its catchment as a result of restoration efforts but no evidence yet in the water quality and ecological monitoring data (Gray 2011).

Researchshows it can take many years to see improvements

Research has shown that it may take several years, even decades, before improvements are seen in lake water quality following restoration (Hamilton et al. 2004, Fisher et al. 2005, Gibbs and Mackay 2006, Environmental Communications Ltd 2010). In most cases this is because the system is complex and often not fully understood eg, internal nutrient sources from lake sediments, through sediment re-suspension and/or nutrient release under anoxic conditions, or long-term nitrogen inputs from groundwater aquifers, such as in Lakes Rotorua and Taupo (Rowe 2004).

Possible reasons for improved water quality

Peaks in chlorophyll a and nutrients are closely linked to *E. densa*bed collapse, with a small peak in both chlorophyll a and nutrients following the first drop in weed biomass after December 2000 and then a much larger peak in chlorophyll a and nutrients when the weed completely collapsed at the end of 2001. This is not surprising when you consider the amount of nutrients that will be released into the water column from the decaying weed. From 2000 to 2002 the weed biomass went from an estimated 5000 tonnes dry weight to none. Based on a phosphorus content of 0.5% in the weed (Lake Ōmāpere Task Force 1986), this amounts to 25 tonnes of phosphorus being released into the water, which is equivalent to a concentration of 1.25 g/m^3. This sudden release of nutrients is the likely cause of the algal bloom.

It is not definitive on what has caused the improvement in lake water quality both in 1993 and since 2007 but there is several possible reasons and it is likely to be a combination of these:

- algae use nutrients and mussels filter algae from water
- algae, nutrients and sediment have discharged from the lake into the Utakura River, given the flushing time of about eight months, this allows for a relatively substantial loss of internal nutrient load
- loss of nutrients through normal nutrient cycle processeseg, denitrification
- grazing by zooplankton
- climatic conditions.

Some of these are discussed in more detail by Verburg et al. (2012), Ray et al. (2006) and Champion and Burns (2001). The discharge of internal nutrient loads into the Utakura River and the filtering by mussels are the most likely reasons leading to the greatest improvements.

Lessons learnt

This report and previous reports (Verburg et al. 2012, Champion and Burns 2001, Ray et al. 2006) highlight the complexity of the problems in Lake Ōmāpereeg, water quality, switching state of the lake, invasive weeds, filtering ability of mussels and algal blooms, and therefore the importance of a well-designed monitoring programme of not just water quality but also ecological condition and biological community health.

This report and research (Environmental Communications Ltd 2010) shows that it is difficult to directly link improvements in water quality to specific actions. Again this highlights the importance of a well-designed monitoring programme, including baseline (or pre-restoration) data, flow data to calculate loads, rainfall event sampling and routine sampling at an adequate number of sites.

As there is no evidence to directly link a specific action to an improvement and the improvements in water quality are not likely to be due to restoration efforts, it is difficult to determine whether one action/intervention alone would achieve improved lake health or whether a package of interventions are needed.However, it is likely that a package of actions/interventions is needed to improve the health of the Lake Ōmāperegiven the complexity of the problem. This is consistent with research (Environmental Communications Ltd 2010).

There are different mechanisms by which nutrients and sediment are reaching the lake eg, TP and SS during rainfall events, whereas nitrogen is all year in surface flows and groundwater and therefore different techniques are needed to manage this. For example, riparian management will assist with reducing TP and SS run-off into streams during high rainfall events, but is not likely to be as effective at reducing nitrogen. Wetlands can be used as a filter to remove nitrogen before catchment water reaches the lake but nitrogen is most effectively managed on the farm with best management practices eg, nutrient budgeting. Current BMP is to keep as much pasture as possible on paddocks to reduce nutrient and sediment loads to waterways (B. Cathcart, NRC, pers. comm.).

To achieve a high plant survival rate weed control in planted riparian areas is recommended every six months for at least two years after planting and plants should be at least PB2 size or 60 cm high (NZLCT unpublished). The farm plans created as part of this project were probably far more detailed than required. Unfortunately, few landowners can provide feedback on their plan as they have not received them as yet, but the two landowners that did both commented that most of the information is the plan was interesting reading but nothing really that they didn't already know.

Community and landowner support and involvement was pivotal in the success of what was achieved on the ground and therefore keeping them informed of the project and progress is important. Also important is managing people's expectations – most restoration projects, such as this, are long term. It is important to inform landowners and the community that improvements as a result of restoration efforts may take many years to decades (Fisher et al. 2005, Environmental Communications Ltd 2010).

A consistent theme in feedback gained was the effect of changes in NRC and FNDC staff and Lake Ōmāpere Trustees involved in the project. Changes of representatives on the LOPMG often led to cyclic discussions and made it difficult to progress at points in the project. Changes in NRC staff is one reason why some parts of the project were not completed eg, farm plans. This highlights the importance of good documentation and communication by representatives back to their respective organisations. A recent review identified changes in key personnelas a common barrier to effectiveness in catchment management projects (Environmental Communications Ltd 2010).

Several people provided feedback that the project was successful because of the amount of action that was carried out on the ground, eg, fencing and planting, and that this could be put down to the commitment and time given to the project by a few people and the ability of them to get landowner support. Unfortunately, the success of most restoration projects is often attributed to the commitment and time of a few people, often remunerated for their time or representatives of organisations (Gray 2011, Environmental Communications Ltd 2010). This highlights the need and value of having sufficient staff in organisations, such as NRC, NZLCT and DOC to assist with projects prioritised as regionally significant. A project such as this requires one FTE for the first 1-3 years and then substantial supportand/or funding in the years to follow. Environmental Communications Ltd (2010) found securing long term funding (greater than 5-7 years) is critical to the success of integrated catchment management projects but is difficult.

Recommendations

This section presents recommendations for future monitoring and management. They are not presented in an order of priority but it is noted where a recommendation is thought to be a priority. Many of the recommendations are actions in the *Restoration and Management Strategy for Lake Ōmāpere*.

Water quality monitoring

Resume sampling at depth or 75% of depth at one location on the lake, for all parameters except secchi depth, chla, cell counts and toxin testing (these only need to be done at the surface).This is a **priority**.The deeper site is important when the lake is in a macrophyte dominated state, as the macrophyte growth can lead to bottom anoxia events (Champion and Burns 2001, page 26 of Burns et al. 2000). Consider carrying out an entire dissolved oxygen profile and deploying data-loggers to investigate oxygen levels close to the sediment (Verburg et al. 2012). However,the two locations on the lake are essentially the same, so if downscaling of monitoring is required for economic reasons; sampling at one location on the lake could be ceased (see page 82 of Burns et al. 2000).

Sampling frequency could be kept to four to six times a year (refer to comments page 83 of Burns et al. 2000). If cyanobacteria counts continue to stay low in winter as they have done since 2007, then cyanobacteria cell counts and toxin testing could be reduced to when there is a visual appearance of a bloom andbetween the monthsOctober to April inclusive.

With the reduction of cyanobacteria in recent years it is feasible to consider the lake being used for recreational purposes (at the Trustees discretion). If there was interest in the lake being used recreationally, then NRC or LOT would need to consider monitoring the lake for microbiogical water quality (eg, *Escherichia coli*) as well as more frequent cyanobacteria monitoring over summer. There is currently very little microbiological data for the lake.

Continue to sample catchment streams and drains and lake-bed sediments as often as practical and consider the need for accompanying hydrological data. Investigate the potential of carrying out storm event sampling of sediments and nutrients in Parakataio Stream. Also consider sampling streams at springheads for nutrients and investigate the implications of this if the results are high ie, where is the source of this groundwater? NIWA have recently completed a nutrient budget for the lake using available datawith modelling (Verburg 2012). Consider their findings and recommendations in future monitoring and management decisions, for example, monitoring of oxygen using data-loggers.Further catchment monitoring, including water quality and hydrological data of streams and springs in both base flows and storm events, would assist in more accurate calculation of nutrient loads. Based on currently available data it is unclear whether wetland development, on the lake margins and in tributary streams, will reduce the nutrient load enough to improve water quality in the lake (Ray et al. 2006).

Update Lake Ōmāpere water quality pages on regional council website annually. Ensure landowners that want water quality updates and LOT receive these regularly.

Indigenous biodiversity

Continue with routine fish surveys, could reduce frequency to every 3 to 4 years but increase intensity (more sites and different methods eg electrofishing catchment streams), however,do not reduce frequency of surveysif management/eradication of mosquito fish is feasible and desired.

The fish records from the November 2009 survey commissioned by the Regional Council do not appear to be entered into the NZFFD, although there are two NZFFD record sheets at the back of the report. Ensure these sheets are entered into the database.

As part of the next mussel survey, in addition to routine sites surveyed, sample more random locations around the lake particularly closer into the lake margins, to get a better estimation of average mussel density for the lake and mussel distribution.

Clarify whether NIWA still have the native plants propogated from the sediment cores collected in the lake, and if so, consider returning these to the lake now that water clarity has improved.

Integrated catchment management

Provide all relevant landowners with their completed farm plans. Follow up with those that already have theirs to see if they need updating or advice. Encourage farmers to continue using plans and follow through on recommended works. Follow up with significant landowners in catchment that never got a farm plan done but were interested. LOT needs a copy of these farm plans given they are responsible for action two under the strategy. Encourage BMP with all farmers in catchment.

Areas of riparian management identified as needing attention include seed collection, weed/pest control and the development of a restoration plan (NZLCT unpublished). There are two organisations that have already indicated interest in being involved with weed control. Encourage landowners and LOT to take responsibility for weed and pest control, providing them with avenues for support eg, community pest control areas, Weedbusters Small Scale Initiatives Funding and Landcare groups.

Continue to support riparian management initiatives, particularly for those landowners that indicated they were keen to do more riparian management/wetland enhancement when feedback was sought for this report. Completing fencing of the lake margin to exclude stock from the lake should be a **priority**, as currently stock from one of these properties is damaging areas of riparian planting by gaining access along the lake margin.Ensure landowners involved with plant identification in catchment (Forester unpublished) are provided with plant lists as promised. Investigate the potential to re-establish and enhance drained wetlands on the lake margin or establish instream vegetation in catchment waterways to remove nutrients before it reaches the lake, particularly in the south eastern, southern and north western areas of the lake. The likelihood of success in terms of improving water quality in the lake is unclear until a more accurate nutrient budget for the lake is created. However, the enhancement of wetlands will also increase habitat for the Northland mudfish (M. McGlynn, pers. comm.).

Aquatic weed and pest management

Now that clarity has improved in the Lake, implementing the aquatic weed management programme is vital to ensure that the *E. densa* doesn't re-collonise the lake and lead to another lake collapse. Surveillance in the lake and catchment for invasive aquatic weeds should be a **priority**. Frequency of the surveillance in the lake should be increased to at least six monthly but does not need to be a detailed dive survey, checks at high risk and random locations, using the anchor, a rake or similar, would be adequate unless an invasive weed is found. It is critical that action is taken quickly to manage any invasive weeds found and is likely to need the introduction of more grass carp (P. Champion, NIWA, pers. comm.). Surveys in the catchment streams and drains should be done annually, especially in high risk areas eg, near roads, houses and where earthwork machinery has been used. Consider training landowners, Lake Ōmāpere Trustees or volunteers (eg Conservation Corp, school groups) to continue with these surveys.Public awareness and education on the spread of weeds should also be a **priority** including media releases, potentially a brochure to landowners and replacing the sign at the outlet. Review aquatic weed management programme.

Investigate whether management and/or eradication of the mosquito fish is necessary and possible.

Investigate the need and options for clearing out the sediment and plants built up around the rock wall at the outlet. This is a **priority** to ensure plantings are not flooded during heavy rain and to ensure mosquito fish don't get into wetlands containing mudfish. This will also assist with the flushing rate of the lake.

Information dissemination and overall management

Ensure the trust is informed of all monitoring and other activities in the catchment, prior to them occurring. Ensure Trust receives copies of monitoring results and other information the council holds for the lake catchment.Update the following Regional Council webpagewith the progress since the project finished:

http://www.nrc.govt.nz/Your-Council/Council-Projects/Lake-Omapere-Restoration-Project/

Media release and possibly look at follow up letter/pamphlet to landowners and other key stakeholders involved in project to give them an update of progress since project finished.

Consider whether a main contact person at the council is required to coordinate council's activities and to be a key contact for LOT, landowners and key stakeholders. Also consider whether regular meetings with interested parties or a similar group to LOPMG but possibly widening membership to include interested landowners would be useful.

Conclusion

The Lake Ōmāpere Restoration and Management Project was a joint initiative between NRC and the LOT funded by the Ministry for the Environment's Sustainable Management Fund thatstarted in December 2003 and ended in June 2006.The overall aims of the project wereto develop and implement a voluntary lake management strategy that will work towards improving the health of the lake and help establish the Lake Ōmāpere Trustees in their role as Kaitiakitanga. The project had six main outcomes, including the development of a Lake Ōmāpere Management Strategy, weed management programme and integrated catchment management programme, enhancement of indigenous biodiversity, water quality monitoring and reporting and to assist the Trustees in their role as Kaitiaki for the Lake. Detailed work was carried out by LOT, NRC, FNDC, DOC, landowners and many other key stakeholders throughout the project to complete the tasks required by the SMF contract. Substantial work has continued since the project finished.

The project was successful because the majority of SMF project tasks were completed on time within budget, project outcomes/outputs have provided tools that can assist the trustees in their role as kaitiaki, people who have provided feedback on the project have responded that it was successful, a substantial amount of riparian management has been undertaken, most farmers in the catchment that weren't already doing BMP, have improved their farming practices and riparian management has led to enhanced indigenous biodiversity in the catchment.There would not have been as much achieved in the same timeframe if an entirely regulatory approach was used instead of the voluntary approach, however, there is evidence that suggests that the use of some regulatory mechanisms is required to gain 100% success.

From July 2003 to June 2010, over $630,000 has been used to undertake the project tasks and on-going work since the project finished. Additionally, over 10,000 inkind hours have been contributed.This includes contributions from NRC, LOT, FNDC, DOC, TRAION, NgaWhenuaRahui, MFE, landowners and other key stakeholders and organisations. The project was successful due to the voluntary process followed, the community and landowners involvement and support, and the commitment and time of a few people in key organisations. This highlights the need and value of having sufficient staff in appropriate organisations to coordinate or assist with regionally significant restoration projects and the need for on-going support and funding to carry out the work. It is unclear whether a regulatory approach would have had a lower or highercapital cost than the voluntary process followed. However, a regulatory approach is likely to have required less inkind contributions from key organisations, landowners and the community.

Lake water quality has improved since 2007 but this is most likely as a result of a natural phenomenon in the lake with the state switching between algal dominated and macrophyte dominated, rather than due to the project and restoration efforts. The available data suggests lake sediments still contain high nutrient levels, which provide an internal nutrient source through the wind resuspending sediment into the water column. The data also shows that the external inputs into the lake have not improved. Nutrient levels in catchment streams and drains are still high. Mussel numbers are stable in the lake and as they can filter algae from the water column, they are likely to be one of the main reasons for the lake improving.

Research shows that it can take many years, even decades to see improvements in water quality as a result of restoration efforts. In many lakes, while changes in the catchment will work towards reducing external inputs to the lake, sustained improvement will not be achieved until the nutrients from the sediment have been removed from the lake system.

This report has also highlighted that the effectiveness of riparian management varies depending on what objectives are trying to be achieved and in most cases should be used in conjunction with other management practices to be successful eg, wetlands to remove nitrogen and encouraging landowners to use BMP.This also highlights the importance of setting realistic objectives, clearly communicating to key stakeholders on how long it could take to achieve these objectives and reporting on progress.

Although there is no evidence that can link improvements in lake water quality to the project, the strategies and programmes developed as part of the project are critical to ensuring the lake remains stable in this improved water quality state or even better improves further. For example, the weed management programme is vital to ensuring that oxygen weed and other invasive aquatic weeds are kept out of the lake and its catchment. The aim with any restoration project should be to achieve sustained improvement.

Several recommendations for future monitoring and management are made. The few considered to be of highest priority are: resuming sampling at 75% depth; completing the fencing of the lake margin; weed surveillance in the lake and catchment waterways; public awareness on the spread of aquatic weeds and maintenance of the rock wall at the outlet.

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Abbreviations

BMP	Best Management Practice
NH_4	Ammoniacal nitrogen
DOC	Department of Conservation
DRP	Dissolved reactive phosphorus
FNDC	Far North District Council
FTE	Full Time Equivalent
LOPMG	Lake Ōmāpere Project Management Group
LOT	Lake Ōmāpere Trust
MFE	Ministry for the Environment
MOU	Memorandum of Understanding
NIWA	National Institute of Water and Atmospheric Research
NNN	Nitrate nitrite nitrogen
NRC	Northland Regional Council
NZFFD	New Zealand Freshwater Fish Database
NZLCT	New Zealand Landcare Trust
OAG	Office of the Auditor General
SMF	Sustainable Management Fund
SS	Suspended solids
TLI	Trophic Level Index
TN	Total phosphorus
TP	Total nitrogen
TRAION	Te Runanga a Iwi o Ngapuhi
VSS	Volatile Suspended Solids

Appendix A - SMF project tasks

Table 11: Tasks required under the SMF contract with the Ministry for the Environment, with brief comment on completion success

Development of Lake Ōmāpere Management Strategy		
Task 1.1 Consultation with landowners, organisation and the wider community on issues and options including:	a) Discussion with all landowners, organisations, school and other community groups to explain project, gain support and identify visions for the lake b) Formation of Project Group c) Hui-a-iwi to explain and launch project, gain support and identify visions for the lake d) Documentation of discussions e) Media release	All tasks completed by due date (June 2004), except public meeting held on 1 July 2004
Task 1.2 Redevelop kaitiakitanga for the lake by:	a) Research of models. Discussion and development of strategies to address issues b) Kaitaki to attend integrated catchment workshop c) Hui-a-iwi to identify issues and options d) Document discussions	All tasks completed by due date (June 2004), however, the actual development of strategies to address kaitiakitanga issues was limited
Task 1.3 Document draft Strategy including:	a) Research background information b) Create draft strategy c) Circulate to stakeholders for comment d) Revise draft and publish draft Strategy	Tasks a, b and c completed by due date (January 2005), including additional task added via contract variation; to hold a second series of Hui-a-iwi for feedback on issues raised at first Hui and introduce draft strategy. Task d completed by June 2006
Task 1.4 Development of Kaitiakitanga model	a) Document draft model b) Circulate to affected parties for comment and discuss as required c) Revise draft as needed and produce final model	Tasks incorporated into Tasks 1.3 and 1.5
Task 1.5 Documentation of restoration and management including:	a) Revise draft strategy if required and produce final Strategy b) Final report on the project c) Meeting and field day to present results d) Hui-a-iwi to present results e) Media release	Task was extended by 6 months to July 2006. Tasks a, c, d and e completed by September 2006. Task b not completed
Development of Weed Management Programme		
Task 2.1 Survey aquatic weeds	a) Two surveys of aquatic weeds in Lake b) Survey of weeds in catchment streams and Lake outlet c) Interpretation of results	Tasks a and c completed by due date (June 2004), however, only 1weed survey in lake was warranted and done as no weeds were found in first survey. Task b completed in November 2004
Task 2.2 Survey of grass carp population	a) Plan to estimate carp numbers b) Fieldwork c) Reporting of results with recommendations for management	All tasks completed by due date (January 2005)
2.3 Develop and implement weed management programme	a) Documentation of grass carp and weed management programme b) Fish removal	Both tasks completed by due date (June 2005)
2.4 Future monitoring and public awareness including:	a) Future weed monitoring programme set up for trustees and fisherman, including training as required b) Public awareness on preventing the spread of weeds by presentations, signage and media release	Both tasks completed by due date (January 2006), however, very little training occurred but both training and the weed management programme are actions in final strategy. Public awareness was limited.

Table 11 cont.: Tasks required under the SMF contract with the Ministry for the Environment, with brief comment on completion success

Integrated catchment management		
Task 3.1 Consultation with and provision of information to landowners including:	a) Research options for management contracts/plans for farmers and sources of information b) Meeting with all landowners. Discuss options and gain support c) Farmers to complete questionnaire to be used in development of plans	All tasks completed by due date (June 2004). 18 landowners (90% of catchment) were visited (LOPMG 2004). 23 landowners were not visited, of which at least 14 have small lifestyle properties. Of the 23, no response or contact was made with 15 and 2 do not want to be involved.
Task 3.2 Develop individual farm management plans with all landowners including:	a) Individual visit to each farm to collect information and discuss issues and requirements for farm b) Plans developed for each landowner using questionnaire results and other relevant information eg photos, maps and nutrient models c) Meeting with each landowner to explain and finalise plan and provide any further information required	Task a completed by due date (January 2005). Task b and c not completed. Mapping of 12 properties was completed by June 2006 and substantial information/advice was provided to landowners. Draft plans were completed for 2 properties by March 2008 but only 1 landowner has received theirs. Final plans completed for a further 8 properties by February 2009 but only 1 landowner has received theirs.
Task 3.3 support and assist with riparian management of the lake and its catchment including:	a) Technical advice for riparian management b) Assistance with funding applications for fencing and riparian planting c) Community education and involvement with planting and fencing d) Follow up on other parts of farm management plans with farmers e) Summary report of riparian management and other farm management practices implemented and their effect. Presentation of results to interested parties and media release	Tasks a, b and c completed by due date (January 2006). Task e completed by September 2006. Task d not completed.
Enhancement of indigenous biodiversity		
Task 4.1 Survey of freshwater mussels and native turf plants including:	a) Plan survey work b) Carry out fieldwork c) Reporting and interpretation of results	All tasks completed by due date (June 2004).
Task 4.2 Investigate potential for enhancement of biodiversity	Research of previous work on freshwater mussel, flax and native aquatic plant population restoration	Completed by due date (January 2005)
Task 4.3 Consultation to establish extent of pest fish including:	a) Consult with local fisherman to gain information on the extent of pest fish in the lake, in particular catfish b) Technical advice from Doc on the need for a survey	Both tasks completed by due date (January 2005)
Task 4.4 Survey of pest fish (TBC after Task 4.3) including:	a) Plan fieldwork b) Carry out fieldwork c) Summarise findings	All tasks completed by due date (June 2005)
Task 4.5 Re-establish freshwater mussels and native plants including:	a) Develop re-establishment programme b) Implement programme c) Monitor success of programme d) Document results e) Media release	Tasks a, b and c partially completed by due date (January 2006), however work was restricted to what the Trustees were happy with in terms of relocating mussels. Experimental trial was unsuccessful, mostly due to the structure being inadequate in dealing with the wind and wave exposure.
Task 4.6 Develop pest fish management strategy and	a) Research pest fish management techniques b) Document strategy	Task not completed as not required.

implement including:	c) Implement strategy	

Table 11 cont.: Tasks required under the SMF contract with the Ministry for the Environment, with brief comment on completion success

Water quality monitoring and reporting		
Task 5.1 Annual routine water quality monitoring including:	a) Bimonthly/monthly water quality monitoring of the lake b) Six monthly water quality monitoring by NIWA c) Potential ongoing monitoring of the Utakura River d) Water quality survey of catchment streams e) Recording and interpretation of results f) Reporting to stakeholders through meetings, panui, website updates and media release every 6 months	All tasks, except b and d, completed for each 6 month due date. b)All monitoring is carried out by NRC, therefore monitoring by NIWA was not required. Algae samples are analysed by NIWA. c) Some sampling was done during project and site was added to regional River Water Quality Network in 2007. d) Sampling of catchment streams and drains did not start until August 2005
Task 5.2 Develop programme for the continual monitoring of Lake and its catchment including:	a) Provide monitoring tools such as LakeSPI and SHMAK kits and training to use them for farmers, community groups and lake trustees b) Establish routine monitoring programme for Lake Ōmāpere and if needed its catchment by NRC	Task b completed by due date (June 2005) Task a was not completed but is an action in the final strategy

Appendix B – Strategy actions

Table 12: Actions from the *Restoration and Management Strategy for Lake Ōmāpere* and achievements to date (as of November 2011)

Action	Individual actions	Action	Comment
1. Water Quality Monitoring (NRC with support from LOT)	Water quality monitoring and annual review	In part	Monitoring completed but overdue for review
	Sharing monitoring information (twice a year on NRC website)	In part	Information made available in AMR (although not twice a year probably adequate given improvements in water quality). Project pages on NRC website need updating, especially to include link to WQ pages
	Survey of groundwater inputs	Y	Completed during project
	Involve trustees in monitoring	In part	Trustees assisted with monitoring regularly during project. However, since project ended trustees have been informed of monitoring but had very little involvement
	Monitoring/studies by other groups	In part	Local schools have been carrying out monitoring on lake and Utakura Environmental group have been doing monitoring of Utakura River, Lake and Harbour
	Develop Cultural Health Index	N	Utakura Environmental Group have done this for Utakura River
	Information on cumulative effects	N	Letter sent to landowners requesting information, nothing further done
	Long term funding/support sources	In part	NRC has funded monitoring since project finished, however future funding is not guaranteed. Other long-term funding sources have not been identified.
2.Environmental Farm Management Plans (LOT with support from NRC)	Process for farm plans	Y	Completed during project
	Contact landowners	Y	Completed during project
	Initial farm visits	Y	Completed during project
	Visits for farmers not available initially	In part	
	Summary of farm plans completed	Y	Completed during project
	Second visits – start mapping	Y	Completed during project
	Nutrient budgets from fert companies	Y	Completed during project
	Develop farm plans	In part	10 plans completed in total, 2 only to draft stage, only 2 landowners have received plans
	Assist landowners with recommendations	In part	Indirectly through assistance given with riparian management component of project
	Update landowners (twice/year)	N	
	Celebration/promotion of success	Y	Celebration evening held on 6 June 2006
	Annual follow up visit	N	
	Partnership and consultation structure	N	
	Encourage landowners to report changes	N	
3.Riparian planting and wetland restoration (LOT with NRC support)	Planting and wetland restoration programme	In part	Report prepared for 2008 and 2009 planting seasons by New Zealand Landcare Trust in 2008
	Plan for weed control in riparian areas	N	
	Plan for pest control	N	

Table 12 cont.: Actions from the *Restoration and Management Strategy for Lake Ōmāpere* and achievements to date (as of November 2011)

4.Aquatic Weed Management Plan (LOT and NRC)	Survey of aquatic weeds in Lake	Y	Completed during project
	Survey of aquatic weeds in catchment streams	Y	Completed during project
	Aquatic Weed Management Programme	Y	Completed during project
	Cost benefit analysis of control methods	In part	Brief comparison of methods completed during project
	Review Weed Management Programme	N	Due for review in 2011/2012
	Undertake weed control as required	NR	
	Lake survey every 2 years	Y	Weed surveys completed in 2004, 2005, 2007 and 2010 by NRC
	Catchment survey (annually)	N	
	Public awareness/education	N	
	Warning signs on weed spread	Y	Completed during project, although one sign needs replacing
5.Enhancement of native plants and animals (LOT and NRC)	Mussel survey	Y	Mussel surveys completed in 2004, 2005, 2007 and 2010 by NRC
	Report on mussel populations	Y	Completed during project
	Discuss issues such as reseeding	In part	Discussions started during project but left with LOT to discuss further
	Experimental trials	Y	But unsuccessful
	LOT make decision on reseeding	NR	
	Native fish surveys	Y	Completed in 2005, 2007, 2009 and 2011 by NRC and 2008 by Utakura Environmental Group.
	Review of bird and invertebrate surveys	Y	Completed during project
	Sediment samples collected for seeds	Y	Completed during project
	Germination experiment	Y	Completed during project
	Options for holding aquatic plants	Y	Completed during project
	Implement preferred option for plants	Y	Plants provided to Lake Ōmāpere Trustee to maintain in plant nursery, however plants did not survive.
	Identify future enhancement projects	N	
5. cont. LOT will:	Develop/maintain nursery and seed collection	Y	Completed during project
	Use plants propagated for catchment	Y	Completed during project
	Opportunities for research by students	N	
6.Pest fish Management Strategy (LOT with advice from NRC)	Plan carp removal process	Y	Completed during project
	Obtain permit	Y	Completed during project
	Pest fish surveys	Y	As above for native fish surveys
	Pest fish Management Strategy	N	
7.Downstream impacts (LOT with support from NRC)	Report on management options	Y	Completed during project
	Identify options that are feasible	N	

Table 12 cont.: Actions from the *Restoration and Management Strategy for Lake Ōmāpere* and achievements to date (as of November 2011)

8.Knowledge Base (LOT with support from NRC)	Promote Wananga	N	
	Database of Lake Ōmāpere information	N	
	Investigate website development	N	
	Updates on NRC website (twice/year)	N	
	Investigate scientific knowledge transfer to Trustees	N	
	Investigate cultural knowledge transfer to Trustees	N	
	Education/awareness campaign on spread of weeds	N	
	Orientation programme on Strategy for new Trustees	N	
9.Health and wellbeing (LOT with support from NRC)	Investigate MOUs on notifiable illnesses	N	
	Liaise with health Trustees	N	
	Investigation of illnesses that could result from poor water quality	N	
10.Investigation into Lake Level (LOPMG)	Research on historic levels	Y	Completed during project
	Mapping/modelling of lake level	Y	Completed during project
	Surveys of title boundaries	Y	Completed during project
	Report on implications of lake level rise	N	
	LOT will consider LOPMG report	N	
11. Outlet structures (LOT with advice from NRC)	Discuss maintenance of rock wall	Y	Completed during project
	Monitor staff gauges	Y	
	Identify contractors	N	Priority
	Repair rock wall	N	
	NIWA proposal on improving downstream water quality	Y	Completed during project
	Investigate alternative to rock wall	N	
12.Information sharing (LOT and NRC)	Options for maintaining links	N	
	Develop memoranda/protocols	N	
	Investigate options and prepare procedure for ongoing info sharing	N	
	Info provided at least twice/year	N	
	Points of contact or centralised contact point	N	
	Strategy for school involvement	N	
12. cont. LOT will:	System for informing new landowners	N	
	Information placed on LIM reports	N	
13.Hapu Involvement	Identify and communicate with hapu	N	

(LOT)			

Table 12 cont.: Actions from the *Restoration and Management Strategy for Lake Ōmāpere* and achievements to date (as of November 2011)

14. Public Access to the Lake (LOT with support from NRC)	Investigate options for public access	N	
	Investigate types of access and lake use	N	
15. Training (LOT with support from NRC)	Aquatic weed control and identification training	In part	Completed during project, however trustees have commented that they do not feel they were trained in this adequately to be able to continue with routine weed surveys
	Training in OSH requirements	N	
	Training in aquatic plant germination	N	
	Trustees to pass on knowledge gained	In part	
16.Regulatory organisations Understanding of Process (LOT with support from NRC)	Korero at Council meetings	N	
	Involved in planning/regulatory processes	N	
	New staff informed on Lake Ōmāpere	N	
	Databases tagged with advisory notes	N	
	Trustees are informed early of planning/regulatory processes	N	
17.Funding and support 2004/2005 (LOT and NRC)	Allocate SMF funding	Y	Completed during project
	Reporting to MFE	Y	Completed during project
	Review and revise project costs	Y	Completed during project
18.Funding and support 2006 onwards (LOT with support from NRC)	Priority areas where funding is required	N	
	Identify and apply to funding sources	N	
	Identify resourcing requirements	N	
19. Review of the strategy (LOT and NRC)	Annual strategy review	N	
	Review of strategy on request	NR	
	Update/amend strategy as required	N	

Appendix C –Results for current state and trends

Current state of water quality

Table 13: Average water quality results for sites 106461 and 106463 combined for the last year (October 2010 to September 2011), last 3 years (October 2008 to Sept 2011) and last 5 years (Oct 2006 to Sept 2011)

	Last year	Last 3 years	Last 5 years
Chla (mg/L)	0.005	0.005	0.020
Secchi (m)	0.73	0.68	0.53
TN (mg/L)	0.50	0.59	1.01
TP (mg/L)	0.09	0.13	0.15
SS (mg/L)	22.57	24.44	45.20
VSS (mg/L)	4.00	6.14	11.86
TLI	4.79	4.98	5.46

Estimated total nutrients in water column

Based on estimated volume in the lake of approximately 20 x 10^6 m^3 and the average nutrient levels in the lake for the last three years.

TN = 20 x 10^6 x 0.59

= 11.8 tonnes

TP = 20 x 10^6 x 0.13

= 2.6 tonnes

Long term trends in water quality

Table 14: Trend results for all data available (varies for site and analyte) for Lake Ōmāpere. Only DO (mg/L) and temperature showed seasonal patterns and therefore the Seasonal Kendall was used. For all other analytes the Mann Kendall trend test was used. P-values significant at 5% level are shown in red and bold. Trends with a change greater than 1% of the median are shown in blue and bold.

Analyte	Site	Start date	End date	n	Ties	Median	*p* value	Median annual change	Change yr^{-1}/ median (%)
Chla (mg/L)	106461	12/02/92	22/09/11	145	46	0.014	0.191	0.0003	1.9
	106463	12/02/92	22/09/11	144	45	0.016	0.107	0.0004	2.3
pH	106460	22/04/92	1/09/08	123	63	7	**0.018**	0.021	0.3
	106461	12/02/92	22/09/11	143	77	7	0.633	0	0.0
	106462	22/04/92	1/09/08	122	55	7	**0.029**	0.021	0.3
	106463	12/02/92	22/09/11	144	73	7	0.668	0	0.0
Secchi (m)	106461	12/02/92	22/09/11	134	56	0.4	0.251	-0.0054	-1.4
	106463	12/02/92	22/09/11	130	53	0.4	0.149	-0.0064	-1.6
TN (mg/L)	106460	22/04/92	1/09/08	113	27	0.98	**< 0.0001**	0.065	**6.6**
	106461	12/02/92	22/09/11	136	31	0.803	**0.015**	0.018	**2.2**
	106462	22/04/92	1/09/08	111	29	0.92	**< 0.0001**	0.070	**7.7**
	106463	12/02/92	22/09/11	135	33	0.79	**0.026**	0.017	**2.1**
TP (mg/L)	106460	22/04/92	1/09/08	123	28	0.087	**< 0.0001**	0.0079	**9.2**
	106461	12/02/92	22/09/11	144	41	0.077	**< 0.0001**	0.0051	**6.6**
	106462	22/04/92	1/09/08	122	26	0.084	**< 0.0001**	0.0066	**7.8**
	106463	12/02/92	22/09/11	145	40	0.078	**< 0.0001**	0.0045	**5.8**
SS (mg/L)	106461	19/01/93	22/09/11	137	28	28	**0.007**	0.828	**3.0**
	106463	19/01/93	22/09/11	136	28	31	**0.001**	1.530	**4.9**
VSS (mg/L)	106461	19/01/93	22/09/11	103	44	6.9	0.253	0.094	1.4
	106463	19/01/93	22/09/11	102	37	7.55	**0.030**	0.236	**3.1**
TLI	106461	12/02/92	22/09/11	122	0	5.66	0.062	0.032	0.6
	106463	12/02/92	22/09/11	119	0	5.53	**0.048**	0.032	0.6
DO% (% sat)	106460	22/04/92	1/09/08	109	9	94.65	**0.009**	-0.337	-0.4
	106461	12/02/92	22/09/11	130	14	95.73	**0.015**	-0.232	-0.2
	106462	22/04/92	1/09/08	109	5	95.17	**0.008**	-0.337	-0.4
	106463	12/02/92	22/09/11	131	11	95.7	**0.003**	-0.279	-0.3
Cell counts (n/100mL)	106463	6/01/04	22/09/11	61	1	6327	**< 0.0001**	-4722	**-74.6**
DO (mg/L)	106460	22/04/92	1/09/08	117	1	9.12	**< 0.0001**	-0.053	-0.6
	106461	12/02/92	22/09/11	139	1	9.4	**0.0005**	-0.033	-0.3
	106462	22/04/92	1/09/08	117	2	9.27	**0.0005**	-0.047	-0.5
	106463	12/02/92	22/09/11	139	2	9.4	**< 0.0001**	-0.044	-0.5
Temp (°C)	106460	22/04/92	1/09/08	118	0	16.9	**0.034**	0.060	0.4
	106461	12/02/92	22/09/11	139	0	17.1	**0.019**	0.066	0.4
	106462	22/04/92	1/09/08	116	1	16.9	**0.036**	0.058	0.3
	106463	12/02/92	22/09/11	137	1	17	**0.042**	0.050	0.3

Table 15: Trend results for all data available, excluding when lake was in macrophyte dominated clear water state (January 1994 to November 2001). Mann Kendall trend test used. P-values significant at 5% level are shown in red and bold. Trends with a change greater than 1% of the median are shown in blue and bold.

	Site	Start date	End date	n	ties	**Median**	***p* value**	**Median annual change**	**Change yr^{-1}/ median (%)**
Chla	106461	12/02/92	22/09/11	95	23	0.029	**0.0003**	-0.002	**-6.9**
	106463	12/02/92	22/09/11	94	23	0.028	**0.0003**	-0.002	**-6.8**
SS	106461	19/01/93	22/09/11	88	16	42.5	**0.0008**	-2.956	**-7.0**
	106463	19/01/93	22/09/11	87	18	44.0	**0.0426**	-1.799	**-4.1**
VSS	106461	19/01/93	22/09/11	67	27	12.0	**0.0001**	-1.508	**-12.6**
	106463	19/01/93	22/09/11	65	25	11.0	**0.0144**	-0.966	**-8.8**
TN	106461	12/02/92	22/09/11	95	28	1.16	**0.0004**	-0.107	**-9.3**
	106463	12/02/92	22/09/11	94	32	1.17	**0.0024**	-0.068	**-5.8**
TP	106461	12/02/92	22/09/11	96	18	0.11	0.4512	0.001	0.8
	106463	12/02/92	22/09/11	96	21	0.11	0.6304	0.001	0.5
TLI	106461	12/02/92	22/09/11	87	0	5.9	**0.0026**	-0.061	**-1.0**
	106463	12/02/92	22/09/11	83	0	6.0	**0.0067**	-0.047	-0.8
Secchi	106461	12/02/92	22/09/11	93	47	0.30	**0.0001**	0.014	**4.5**
	106463	12/02/92	22/09/11	88	43	0.30	**0.0005**	0.009	**3.1**

Appendix D – Algal community dominance

Table 16 –Five most abundant algae species in samples from Lake Ōmāpere (site 106463). BG = Blue green

Date	1	2	3	4	5
12/03	BG	BG	Diatom	Diatom	Other
01/04	BG	BG	Green	BG	BG
02/04	BG	Green	Other	Diatom	BG Other
03/04	BG	BG	Green	Diatom	
04/04	BG	Diatom	Green	Desmid	Green
05/04	BG	Diatom	Diatom	Desmid	Green
07/04	BG	Diatom	Diatom	Green	
08/04	BG	Diatom	Diatom	Green	
09/04	BG	Diatom		BG	BG
10/04	Diatom	Green	BG	BG	BG
11/04	BG	BG	BG	BG	Diatom
12/04	BG	BG	BG	Green	Diatom
01/05	BG	BG	Diatom	BG	Green
02/05	BG	BG	BG	Green	Diatom
03/05	BG	BG	BG	BG	Green
04/05	BG	Diatom	Green	BG	Desmid
05/05	BG	BG	Green	BG	Diatom
06/05	BG	BG	BG	Diatom	Diatom
07/05	BG	BG	BG	Diatom	Diatom
08/05	BG	BG	Green	Desmid	Diatom
09/05	Desmid	Diatom	Green	Desmid	Green
10/05	Diatom	BG	Desmid	Green	BG
11/05	BG	BG	BG	BG	Green
12/05	BG	BG	BG	Green	Diatom
01/06	BG	BG	BG	Green	Desmid
02/06	BG	BG	BG		Desmid
03/06	BG	BG	Green	BG	Green
04/06	BG	BG	Green	Diatom	Green
05/06	BG	Green	BG	Desmid	Diatom
06/06	BG	Green	BG	Diatom	Diatom
08/06	BG	Diatom	Green	Green	BG
09/06	BG	Desmid	BG	BG	Diatom
11/06	Green	Diatom	Green	BG	BG
12/06	BG	BG	Green	BG	Desmid
01/07	Green	BG	BG	BG	Green
03/07	Green	BG	BG	Green	Diatom
04/07	Desmid	Other	Green	Diatom	Other
06/07	Green	Other	Green	Diatom	Green
08/07	Desmid	Other	Green	Green	Diatom
10/07	Diatom	Desmid	Desmid	Diatom	Other
12/07	Diatom	Diatom	Green	Green	BG Other
02/08	BG	Other	Diatom	Diatom (2)	Desmid
03/08	Diatom	Green	Diatom	Desmid	DiatomGreen
04/08	Diatom			Diatom	BG
07/08	Diatom		Green (2)	Green Other	DiatomGreen
09/08	Diatom (2)		Green	DiatomGreen (2) Other	Diatom (2)Green (2) Other
12/08	Green (2) Other	BGGreen	Green (2)	Green	
03/09	Green			Diatom	Green
06/09	Other			Diatom (2)Green	
09/09	BG			Desmid Other	
11/09	Diatom		Green		Diatom Green
12/09	BG	Diatom	GreenOther	Green	
01/10	BG		Other	DiatomGreen (2) Other	Diatom
02/10	BG	Diatom	Other		Diatom
04/10	Other	Diatom		Diatom (2)	Diatom (2)Green
06/10	Diatom	Diatom Other	DiatomGreen	Diatom	Diatom
08/10	Other			Diatom	Green (2)
10/10	Other	Diatom		Green	Diatom
11/10	Other	Green		Green	DiatomGreen
12/10	Other			DesmidDiatom	Green
01/11	Desmid	Other			Diatom
03/11	BG				
04/11	Diatom	BGDiatom	Other	Diatom (2)	Diatom
06/11					
07/11	Other	Other			Green
09/11	Other	Green	Diatom	Diatom	

Appendix E – Nutrients in lake sediments

Comparison with other lakes

Table 17: Average and maximum levels of TN and TP in Lake Ōmāpere sediments compared to levels published for other lakes in New Zealand and overseas.

Study	TN average (g/Kg)	TN maximum (g/Kg)	TP average (mg/Kg)	TP maximum (mg/Kg)
Lake Okeechobee (Fisher et al. 2005)	5.37	28	250.9	958
12 Te Arawa lakes (Hickey and Gibbs 2009)	10.35	18.87	1869	3489
Lake Rotoiti (Chittenden et al. 1976)	NA	4.0	963	1490
Lake Rotoroa (Chittenden et al. 1976)	NA	5.4	784	1210
Lake Brunner (Chittenden et al. 1976)	2.2	NA	1330	NA
Lake Taupo (Viner 1989)	2.2	3.3	700	1700
Lake Ōmāpere	2.8	5.8	280.6	519

Estimate of nutrients in top layer (2 cm) of sediment

Assumptions:

1 mg/kg (dry weight) equals at least 1 g/m^3 as a volume (fair assumption given a kilogram of sediment will be less than a litre in volume).

Area of sediment available for re-suspension approximately 10 million m^2 (assuming shallow areas on margins and sheltered bays are not as vulnerable to re-suspension)

Average TN $= 2800 \times 0.02 \times 10 \times 10^6$

$= 560$ tonnes

Average TP $= 280 \times 0.02 \times 10 \times 10^6$

$= 56$ tonnes

Appendix F – Catchment water quality

Table 18: Summary of nutrient results for catchment streams and farm drains.Range and median shown (where appropriate) with number of samples in parentheses.Results shown in red and bold are greater than the levels for a eutrophic lake (ie, TN > 725 mg/m^{3}and TP > 43 mg/m^3). Includes samples since August 2005 and includes results from NIWA survey in May 2006 for sites 108386, 108387 and 108388.

NRC Site	DRP(mg/m^3)	NH_4(mg/m^3)	NNN(mg/m^3)	TN(mg/m^3)	TP(mg/m^3)
108385 (S end of lake)	All <10(4)	All ≤ 30 (3)	60 –310 (3) Median = 100	290 –560 (4) Median = 450	14 –39 (4) Median = 18
108386 (N end of lake)	14 – 39 (5)	All ≤ 30 (4)	All < 60 (4)	400 – 700 (4) Median = 650	22 – **51** (4) Median = 39
108387 (Parakataio Stream @ Te Pua Rd)	2 – 199 (10) Median = 5	5 – 65 (9) Median = 8	284 – 1280 (10) Median = 773	60 – **1640** (10) Median = **1050**	11 – **360** (10) Median = 20
108683 (NE end of lake)	All < 10 (5)	10 – 70 (4) Median = 28	841 – 1660 (4) Median = 1290	57 – **2000** (5) Median = **1360**	All < 18 (5)
108827 (S end of lake)	All < 4 (2)	All ≤ 10 (2)	12 – 164 (2)	400 (2)	4 – 29 (2)
108684 (SE end of lake)	20 (1)	20 (1)	11 (1)	400 (1)	**108** (1)
108685 (Parakataio Stream by lake edge)	9 – 33 (2)	All ≤ 40 (2)	57 - 137	600 – 637 (2)	**59** – **124** (2)
102990 (Parakataio Stream @ Te Pua Road)	NA	160 – 3330 (3)	NA	NA	NA
108388 (drain by Te Pua Rd)	68 – 129 (2)	110 – 1380 (2)	1070 – 1380 (2)	**1880** (1)	**230** (1)

Table 19: Summary of water quality results from flood event sampling carried out from June 1995 to June 1996 (NRC 1996).

Date	Start time	Sampling duration (min)	Average flow for sampling duration (l/s)	Volume sampled (m^3)	SS (g/m^3)	NNN (g/m^3)	TP (g/m^3)	Comment
29/06/1995	1911	20	473	600	215	NA	NA	6 samples bulked into 1, error in time corrected
2/07/1995	1158	55	632	1800	200	NA	NA	18 samples bulked into 1, error in date and time corrected
12/07/1995	1930	43	576	1440	617	NA	NA	12 sampled bulked into 1
9/08/1995	0515	112	572	3600	185	0.56	1.526	12 samples bulked into 2 and averaged for WQ results
6/09/1995	1826	351	1045	22684	204	0.379	1.221	WQ results is relative average of 3 sets of 14 samples: 1 was 4 samples bulked, 1 was average of 5 samples and other was average of 5 samples
25/10/1995	1703	672	698	28000	86	0.39	0.673	24 samples bulked into 1
24/11/1995	1237	330	420	6600	376	0.247	0.813	WQ results relative average of 2 sets of samples (15 samples bulked and 7 bulked)
22/12/1995	1215	107	1113	7200	248	NA	NA	24 samples bulked into 1
22/02/1996	1122	105	153	1200	80	0.4	0.545	4 samples bulked into 1
3/03/1996	0230	0	145	300	77	NA	NA	1 sample only
21/05/1996	1326	693	216	7740	374	0.676	1.213	WQ results relative average of 2 sets of samples (15 samples bulked and 9 bulked)
22/05/1996	1550	217	333	4800	117	1.11	0.544	16 samples bulked into 1
22/06/1996	1110	84	323	1800	296	0.85	0.893	6 samples bulked into 1
25/06/1996	0640	169	376	3900	100	0.66	0.793	13 samples bulked into 1

Estimate of nutrient loads to the lake from Parakataio Stream

Hourly at base flows

Average flow rate = 29 l/s(Based on monthly average flows for August 1994 to June 1996)

Median NNN = 0.773 mg/land median TP = 0.02 mg/l (based on water quality data since 2005 - see table 18 above)

NNN = 0.773 x 29 x 3600

= 80 g/hour

TP = 0.02 x 29 x 3600

= 2.1 g/hour

Hourly at high flows

Example 9/8/95, event sampled for 112 minutes, see table 19 above for data

NNN = 0.56 x 572 x 3600

= 1153 g/hour

TP = 1.526 x 572 x 3600

= 3412 g/hour

Example 6/9/95, event sampled for 351 minutes, see table 19 above for data

NNN = 0.379 x 1045 x 3600

= 1426 g/hour

TP = 1.221 x 1045 x 3600

= 4593 g/hour

Appendix G – Approximate water balance

Data used

Based on following data:

Lake area = 11.6 km^2

Catchment area (minus lake area) = 21.1 km^2

Mean annual rainfall = 1844 mm (NRC site 535817 – Waitangi @ Ohaeawai)

Annual total penman potential evapo-transpiration (Site Kaikohe AWS, agent no. 1134, Source: Cliflo, NIWA) in 2005 = 937.7, 2006 = 834.6 and 2009 = 957.2.

Average evapotranspiration = 910 mm

Annual total penman open water evaporation (Site Kaikohe AWS, agent no. 1134, Source: Cliflo, NIWA) in 2005 = 844.6, 2006 = 773.8 and 2009 = 818.4.

Average evaporation = 812 mm

Estimated volume in the lake ~ 20 x 10^6 m^3 (Lake Ōmāpere Task Force 1986)

Flow at outlet based on 49 spot gaugings from 1928 to 2006 gives an overall average flow of 898 l/s, while the average of monthly averages gives a flow of 1130 l/s.

Annual inflows (m^3/year)

Lake = 1.032 x 11.6 x 10^6

= 11.9712 x 10^6

Catchment = 0.934 x 21.1 x 10^6

= 19.7074 x 10^6

Total = 31.6786 x 10^6

The Lake Ōmāpere Task Force (1986) report estimated the annual inflows to be 27.3 x 10^6 m^3/year.The annual catchment inflow equate to catchment inflow of 624 l/s. Based on the limited data available for Parakataio Stream the average flow rate is 29 l/s (calculated from monthly averages of 15 minute interval automatic flow recorder data between August 1994 and June 1996 at site 47706). The other small streams and drains into the lake were estimated to be flowing at about 1-2 l/s in February 1986 (Lake Ōmāpere Task Force 1986).

Discharge rate

This total annual inflow equates to an average discharge rate of 1.0 m^3/s. This is comparable with the average flow calculated from gaugings at the outlet. The Task Force (1986) report estimated the average discharge rate to be 0.87 m^3/s.

Estimated flushing time

Based on average discharge rate of 1.0 m^3/s and volume of 20 x 10^6 m^3a rough estimate of the time for the entire lake to flush would be 231 days. This is similar to the 262 days estimated by the Lake Ōmāpere Task Force (1986) and the 212 days estimated by NIWA (Verburg 2012).

Appendix H–Data analysis and background information

Methods used for analysis

Data cleansing

All data available for the lake was combined for the analysis, including the data collected by NIWA from 1992 to 2000. There were several zero values in the NIWA data– these were all removed and assumed to be no data for that particular analyte and sampling occasion.

From June 2001 to April 2002 three samples were collected at the same time at each site and analysed individually. For this analysis the average of the three results was used.Secchi results have been entered against both the 75% and 25% depth sites. These results were combined and analysed for the 25% depth site for this report. SS results were combined with TSS.

For graphing all less than values were halved and all greater than values were changed to the value plus 10% of the value.

TLI was still calculated if there were three of the fouranalytes required but not if there were only two.TLI was only calculated for the 25th depth sites (106461 and 106463). See formula below for calculation.

Trend analysis

All trend analysis was carried out in Time Trends software. Seasonality plots with a Kruskal Wallis test were used to check for seasonal patterns in data. The only parameters found to have seasonal trends were DO (mg/L) and temperature. This is consistent with Burns et al. (2000), who found that water quality in Lake Ōmāpere over four years (1992 to 1995) showed very little seasonal pattern and was more likely related to weather influencing sediment re-suspension in the lake. Therefore, to test for 19 year trends the Seasonal Kendall test was used for DO and temperature with 12 seasons, while a Mann Kendall test was used for all other parameters.

A trend was interpreted as statistically significant if the p-value was less than 0.05 and a trend was interpreted as environmentally meaningful if the percentage change was greater than the arbitrary value of 1% of the median per year.

TLI information

Formulae for calculating trophic levels

Formulae taken from the protocols developed by Burns et al. (2000):

For Chlorophyll α (Chla): $TL_{Chla} = 2.22 + 2.54 \times \log(Chla)$

For secchi depth (SD): $TL_{SD} = 5.10 + 2.27 \times \log(1/SD - 1/40)$

For total phosphorus (TP): $TL_{TP} = 0.218 + 2.92 \times \log(TP)$

For total nitrogen (TN): $TL_{TN} = -3.61 + 3.01 \times \log(TN)$

Overall Trophic Level Index (TLI) = $\frac{1}{4}(TL_{Chla} + TL_{SD} + TL_{TP} + TL_{TN})$

For three analytes (TLI3) = $1/3\,(TL_x + TL_y + TL_z)$, where x, y and z are each one of Chla, SD, TP or TN.

Values used to define boundaries of trophic levels

This table has been taken from the protocols developed by Burns et al. (2000), however the first three trophic levels have been removed as these are not relevant to Lake Ōmāpere.

Table 20: Values for total nitrogen, total phosphorus, chlorophyll α and secchi depth used to define the boundaries of the different lake trophic levels.

LakeType	Trophic level	Chla (mg/m^3)	Secchi depth (m)	TP (mg/m^3)	TN (mg/m^3)
Mesotrophic	3.0 – 4.0	2.0 – 5.0	7.0 – 2.8	9.0 – 20	157 – 337
Eutrophic	4.0 – 5.0	5.0 – 12	2.8 – 1.1	20 – 43	337 – 725
Supertrophic	5.0 – 6.0	12 - 31	1.1 – 0.4	43 – 96	725 – 1558
Hypertrophic	6.0 – 7.0	> 31	< 0.4	> 96	> 1558