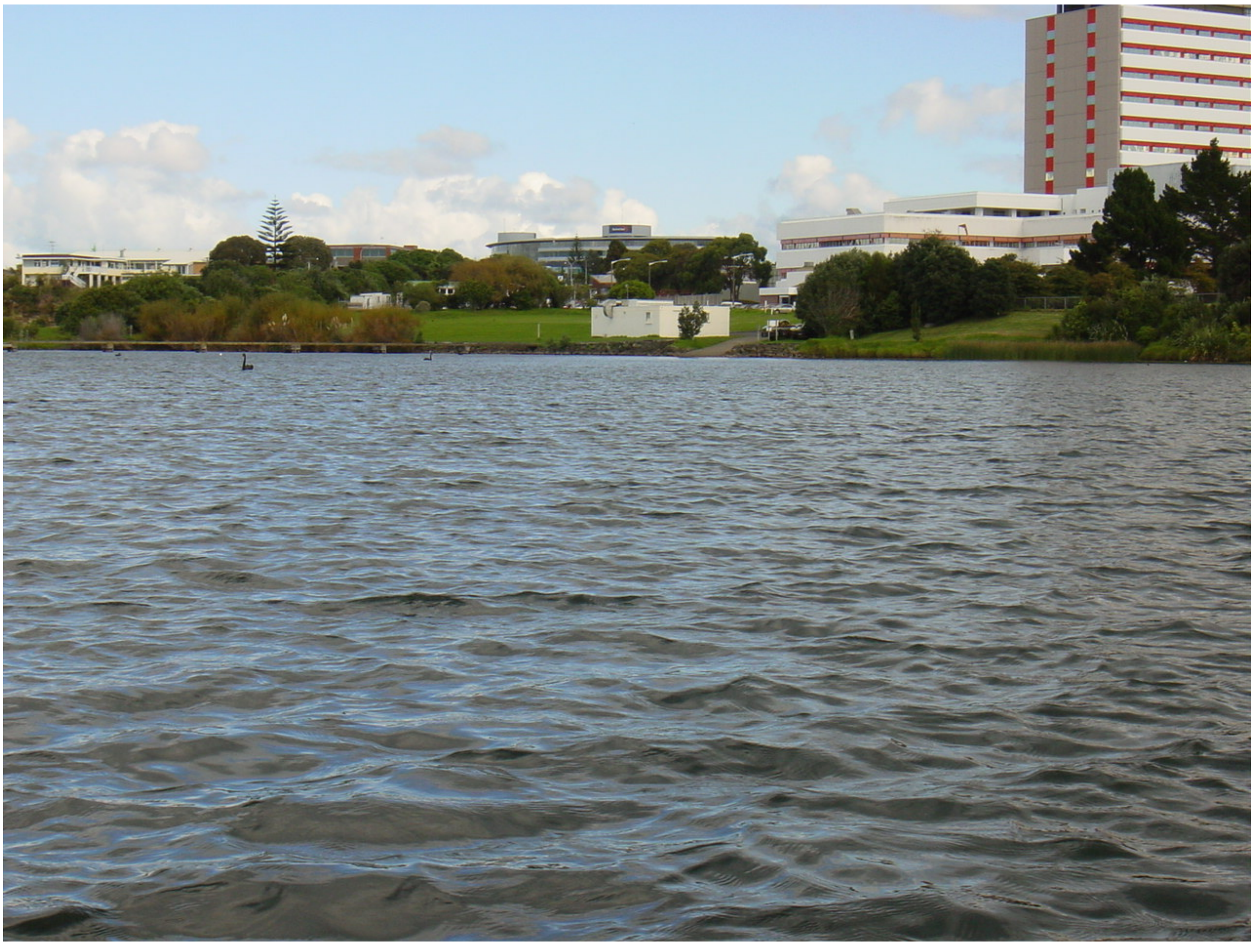
Lake Pupuke Inspection
Report No. KC71



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Lake Pupuke is the only lake of its type within the Auckland region. Sitting in a volcanic explosion crater formed approximately 140,000 years ago, the lake is an important ecological, geological, cultural, recreational and scenic resource. The relatively small surrounding catchment is developed, mainly for residential use. Lake water quality is relatively good in comparison to other lakes in the Auckland Region and has improved since the early-mid 20th century.

Area / Shoreline Length / Depth		110 hectares / 4.3 kilometres / 57 metres
Size Of Catchment		87 hectares
Vegetation Cover		16 hectares (18%)
Imperviousness		36 hectares (41%)
District Plan Zones	**Business**	0.2%
	Recreation	19%
	Residential	49%
	Road	9%
	Special Purpose	23%
Recreational Use		High – mainly water based
Receiving Environment		Subsurface discharge to Thorne Bay
Natural Wetlands		5 lacustrine (lake edge) wetlands
Artificial Wetlands		None. Stormwater treatment wetland proposed
Phytoplankton		At least 96 species recorded, four potentially toxic blue-green algae (cyanobacteria) occur
Macrophytes		Dominated by introduced eel grass *Vallisneria gigantica* and oxygen weed *Egeria densa* – management issues
Macroinvertebrates		Variety of species
Fish		Native – eels and common bully; variety of introduced species
Birds		Abundant and diverse range use lake and surrounding reserves for feeding and roosting

Riparian Vegetation	Limited
Shoreline Modification	44% of shoreline lined or reinforced
Shoreline Erosion	Approx. 5% of shoreline has slight erosion
Lake Type	Warm monomictic
Temperature	12 – 22+ ^{o}C, thermally stratified for most of the year
Suspended Solids, Turbidity And Visual Clarity	Relatively clear, low turbidity and suspended solids
Oxygen And Oxygen Demand	Good in upper layer, severely depleted in lower layer during summer / autumn
Trophic Status	Mesotrophic
Contaminants	No data
Bacteria And Pathogens	Generally low faecal coliforms
Sediment Quality	No data

1 INTRODUCTION

1.1 Purpose of Document

This report provides a factual description of the Lake Pupuke catchment based on previous published investigations of the lake and physical inspection by canoe of some 4.3 kilometres of the shoreline during June 2003. Similar types of information were collected in this survey as in the Stream Walk surveys – a detailed list of parameters recorded is provided in Report KC 79. It also describes past, present and proposed future land uses in the catchment and known human use values of the physical environment.

The document forms a key building block of the process to evaluate the freshwater ecosystems of North Shore City and provides a baseline for monitoring changes over time.

An aerial photograph of the overall stormwater catchment in which Lake Pupuke is located is shown on Figure LP-0.

Note that while this report largely follows the format of the other Stream Walk reports, it has been modified to fit the differences between lake and stream environments and the nature of the survey.

1.2 Relevant Supporting Documents May Include

Report N°

KC2 Future Land Use and Population Projections Used for Network Consent Purposes

KC32 Assessment of Constraints to Fish Passage

KC33 Erosion in the Streams of North Shore City

KC35 Environmental and Public Health Risk Assessment Report

KC36 Freshwater and Marine Heritage Report

KC38 Individual Sewage Overflow Assessment Data File

KC39 Individual Stormwater Discharge Assessment Data File

KC47 History of Development of the City Report

KC48 Existing Uses of the North Shore Water Environment

KC49 Affected Parties Consultation Report

KC51 Report on Consultation with Maori

KC52 Overall Consultation Report

KC53 Historical Overview of Lake Pupuke Water Quality and Use for Water Supply

KC54 Lake Pupuke Ecology Report

KC55 Lake Pupuke Geology and Groundwater Report

KC68 CDC 7 Integrated Catchment Management Plan

KC70 Report on the Methodology to Categorise Urban Streams

KC 79 Network Consents Water Monitoring and Reporting Plan

KC116 Lake Pupuke Water Quality and Weed Report (Noel Burns)

KC119 CDC 2 - Preliminary Assessment of the Existing Environment (KMA)

KC124 Preliminary Assessment of Existing Environment

KC125 Ecological Characteristics and Ecosystem Objectives for North Shore City Streams

ARC Baseline Water Quality Stream, Lake and Saline Waters, Jan – Dec 2000 (TP 150), NIWA 2001

ARC Baseline Water Quality Stream, Lake and Saline Waters, Jan – Dec 2001 (TP190), NIWA 2002

ARC Baseline Water Quality Stream, Lake and Saline Waters, Year 2000 (Jan 1992-Jan 2000) (TP 132), NIWA 2000

ARC Lakes Monitoring Programme Review, NIWA Client Report: ARC00256, 1999

Aspects of the limnology of Lake Pupuke - with special reference to the phytoplankton, MSc Thesis in Botany, University of Auckland. Holmes, CC, 1994

Changes in the Water Quality of Lake Pupuke 1966-1990. Auckland Regional Water Board TP 93. W.N. Vant and R.D. Pridmore, Water Quality Centre DSIR, 1990a.

Draft Reserve Management Plan for the Reserves Bordering Lake Pupuke – Pupukemoana, September 2004

Lake Pupuke Stormwater Catchment Management Plan

Management Perspectives on Lake Pupuke. Noel Burns, Seveno Ltd and Brian Coffey, Brian T. Coffey & Associates Ltd. June 2003.

Management Perspectives on Lake Pupuke. Noel Burns, Seveno Ltd and Brian Coffey, Brian T. Coffey & Associates Ltd. June 2003.KC125 Ecological Characteristics and Ecosystem Objectives for North Shore City Streams

North Shore City Ecological Study: A survey of sites of ecological significance in Tamaki and Rodney Ecological Districts. Joint project between Auckland Regional Council, Natural Heritage Section and North Shore City Council. 2005

Plant Nutrients in Lake Pupuke. W.N. Vant and R.D. Pridmore, Water Quality Centre DSIR, 1990b.

Project CARE 1999/2000 North Shore Stream and Stormwater Quality Study – Technical Report 3.05

Results of Monitoring New Zealand Lakes, 1992-1996, NIWA Client Report: MFE80216, 1998

Summer oxygen depletion in Lakes Pupuke and Ototoa during summer 2002-03, with additional data from summer 2003-04 in Lake Pupuke, NIWA Client Report HAM2004-022, 2004

The hydrology of Lake Pupuke. R.A. Hoare & Associates, 1990.

2 PHYSICAL DESCRIPTION OF THE LAKE PUPUKE CATCHMENT

2.1 General Description of the Lake Pupuke Catchment

Lake Pupuke catchment lies just inland of the east coast of North Shore City, adjacent to Thorne Bay and north of Shoal Bay and the Waitemata Harbour, as shown on Figure LP-1. The lake has a total surface area 110 hectares and a circular contributing catchment of only 87 hectares.

The perimeter of the catchment follows the ridge of the 140,000 years old volcanic explosion crater in which Lake Pupuke lies. The boundary runs along Shakespeare Road in the west, crossing from Milford Primary School to the corner of Hurstmere and Kitchener Roads, then follows along to the west of Hurstmere Road, down Killarney Street, to the corner of Killarney Street and Pupuke Road, around the top of Smales Quarry and Quarry Lake, along Taharoto Road and the southern boundary of North Shore Hospital to Shakespeare Road again.

There are no inlet streams to the lake, or surface outlets. Water enters the lake directly during rainfall events and via overland and subsurface flows from the surrounding catchment. The lake discharges via an underground fissure in the basalt rock along the eastern margin of the lake and runs out at Thorne Bay into the Hauraki Gulf.

2.2 Land Use and Development

2.2.1 Past and Present Land Use

For three centuries or more before the arrival of the Pakeha, Maori occupied the area. Lake Pupuke attracted the Maori for the food they could find there including eels, freshwater mussels and birds, for the flax that grew abundantly on the shores, for the beaches nearby with their shellfish and readily accessible fishing grounds, and for the areas surrounding the lake suitable for gardening and the growing of kumura. A Maori portage also once passed from the east coast via Lake Pupuke to Shoal Bay.

The area was purchased by European settlers from numerous Maori owners during the period 1841 to 1844. The wide belt of volcanic soil surrounding the lake was sought after and the area was surveyed quickly, with all lots sold via auction by 1844/1845 to early settlers for development as farms. The area was farmed until the 1920s, and land surrounding the lake was notable for horticulture and agriculture.

In the mid to late 1800s, residential subdivisions began to occur and the area became popular for holiday homes. By the early 1900s, holiday homes began changing to become permanent residences, with the area coming to accommodate an increasing full time population. (KC 47)

In 1958 North Shore Hospital was built and opened. Subdivisions in Sylvan Park Ave, Lake View Road and other areas of the catchment, followed in the 1960s and 1970s.

The lakeside has been subjected to intermittent quarrying of basalt for over half a century, with only one of the quarries remaining open and this is now little used (Smales Quarry). One former working has been flooded to form a lagoon and is now known as Quarry Lake.

Presently, just over half of the 4.3km long shoreline is in private ownership. The remainder of the shoreline is bordered by five Council reserves which provide public access to the lake (Killarney, Sylvan, Kitchener and Henderson Parks and Quarry Lake), plus a number of esplanade reserves totally over 16 hectares, two schools (Carmel College and Milford Primary) and North Shore Hospital.

Table 1
Indicative land use types within the Lake Pupuke Catchment in 2002

District Plan Zone	Area (ha)	Percentage of Total Catchment
Low density residential	33	38%
High density residential	2	2%
Commercial (includes the hospital, schools and quarry)	19	22%
Open space	11	13%
Bush	16	18%
Road	7	8%

2.2.2 Future Land Use and Development

The NSCC City Blueprint (2002) land use model (high growth scenario) projects that the catchment could accommodate an increase in dwelling numbers from 726 dwellings in 2001 to 1558 dwellings by 2021 (a 115% increase), and to 1937 dwellings by 2051 (a 167% increase).

The District Plan makes provision for future land use change at Smales Quarry where quarrying and processing of basalt and scoria occurred for many years. The quarry is recognised as a finite operation which will require land restoration before it can be used for alternative purposes suited to the built up urban area in which it is located. Restoration of the quarry is required prior to any new use or rezoning of the land, and subdivision is currently prohibited to ensure comprehensive rehabilitation of the site occurs.

2.3 Vegetation

Report No. KC 54 ‘Lake Pupuke Ecology Report’, describes the terrestrial flora within the catchment. The report describes vegetation along the lake edge as a mixed native and introduced plants community, with plants managed and planted by residents in places. There are few places around the lake where a natural lake to land vegetation transition occurs.

Some of the parks and reserves bordering the lake support native woodland. Sylvan Park, in particular, has been classified as a Priority Vegetation Site in the North Shore Ecological Study and contains remnant native forest with several fine stands of karaka and kohekohe, as well as puriri, taraire and kowhai.

2.4 Geology and Soils

The geology of the Lake Pupuke catchment is the product of volcanic activity, which occurred some 140,000 years ago (as indicated by thermoluminenscence dating of lava flows). Lake Pupuke is the northernmost volcanic vent within the Auckland volcanic field and is the largest explosion crater on the North Shore and the most complex.

The eruption(s) which formed Lake Pupuke was explosive as the result of rising basalt magma coming into contact with a wet marshy subsoil area, as water suddenly superheated into flashes of steam. Molten lava erupted through vents forming fire fountains, and thin streams of lava flowed out over what is now Hurstmere Road and through a forest (tree moulds in lava can be seen today at Thorne Bay).

There is evidence that the crater was formed by volcanic action from at least two and probably three centres of eruption. Anomalous magnetic readings near the entrance to the semicircular bay on the north-eastern side of Pupuke, suggest this is a small subsidiary explosion crater.

The explosive eruption at Pupuke mantled all of Takapuna and Milford in volcanic material. The ring of tuff and lapilli extends over a considerable area beyond the tuff ring rim of the Lake Pupuke catchment.

2.5 Topography of Catchment

The topography of the catchment is unique within the North Shore and the Auckland region, and is delineated by a tuff ring that surrounds the lake. This ring ranges in elevation from 14 to 34 metres above mean high sea water level to the lake edge, which in winter has an average level of approximately 5.73 metres above mean high sea water. Terrain within the east of the catchment is considerably steeper than other areas and the gradients to the west and north are gentler.

Topography within Quarry Lake and the adjacent Smales Quarry is highly modified as a result of quarrying activities that have occurred in the past. Beyond the catchment boundary the land falls away down the outer face of the volcanic tuff rim, (towards Milford Beach and the Wairau Estuary to the north, Takapuna Beach in the east, Barrys Point in the south, and Wairau Road and the Wairau Creek in the west).

2.6 Imperviousness

Approximately 36 hectares (41%) of the Lake Pupuke catchment has impervious land cover. Impervious surfaces such as roads, roofs and car parks are an unavoidable feature of urbanised catchments. The impacts of increased impervious surfaces on Lake Pupuke may include:

- Reduced infiltration, more surface runoff, less subsurface flow;

- Increased erosion at stormwater outfalls – although the lake edge survey did not identify this as an issue and many outfalls are now below the lake water level as a result of lake levels rising since abstraction for drinking water stopped;
- Less opportunity for natural filtering of water to remove contaminants (such as those from roads) through vegetated riparian areas and soils; and
- Localised increases in water temperature

3 HUMAN USE

3.1 Heritage Values

The Draft Reserve Management Plan for the Reserves Bordering Lake Pupuke (NSCC, 2004) has a detailed section on the heritage of the Lake Pupuke catchment. Following is a brief summary of the key features.

It is believed that 1200AD is the earliest time that Maori may have visited the area from the islands in the Hauraki Gulf and that within 100-200 years they occupied the area on a full-time basis, settling in the vicinity of the lake sometime during the 1400 -1500s. Maori occupation continued for three centuries prior to arrival of the first European settlers in the early 1800s, however very little evidence of the Maori occupation remains.

As mentioned in Section 2.2.1, the lake and surrounding catchment was popular with European settlers, originally being used for agriculture, then holiday homes and then permanent residences. The lake itself was used as a domestic water supply for a period of nearly fifty years. One of the pump houses still remains in Killarney Park on the south shore. Section 4.3.2 describes the implications of abstraction for the lake.

From the time subdivision first began, the catchment attracted wealthy buyers and investors due to the proximity of the lake, sea, the views and the fertile volcanic soils. By the late 1800s, the area was described in the *NZ Graphic* as follows: "the lake itself is really private property, being nearly surrounded by gentlemen's residences, whose wooded grounds fringe its shores". Although much subdivision has happened since then, the area surrounding the lake has become some of the most valuable real estate on the North Shore.

3.2 Areas of Known Cultural Significance

Surveyors have recorded a Maori Papakaiinga (settlement) in the vicinity of the lake and they were also aware of tapu (sacred) caves on the edge of the lake which hosted large numbers of ancestral skeletal remains. Unfortunately the arrival of early settlers brought with it a fascination for collecting Maori artefacts and the burial caves became the target of pillagers which forced the local Maori to relocate their ancestors and taonga (treasures).

Two middens were previously found on the northern banks of the lake, below and to the west of Dodson Ave, and west of Fenwick Ave, and a terrace believed to be of Maori origin is located in Killarney Park. It is also believed that a group of earthworks discovered at the lake during the late 1960s were probably kumara pits, which were levelled with no one realising the significance of the find. There have been reports that in the late 1800s a Maori waka (war canoe) was found on the bottom of the lake.

It is understood that the karaka grove on the northern banks of the lake in Sylvan Park was still being harvested well into the twentieth century and ceremonial blessings carried out in the lake still take place today.

3.3 Recreational Use

Lake Pupuke is one of the city's and the region's greatest environmental assets and is the only lake of its type within the Auckland region. The lake, with its size and as a sheltered body of water, provides an attractive visual and recreational amenity for both residents and the general public, and is the most intensively used lake in the region. It is particularly valuable in terms of its urban context and unique in terms of its close proximity to sandy salt-water harbour beaches. Likewise, its location in such an urbanised environment and closeness to the commercial centres of Takapuna and Milford, is significant in terms of the effects of intensive development and usage on the lake itself.

The lake has been identified as a water body of national importance for tourism by the Ministry of Tourism (http://www.tourism.govt.nz/aboutus/au-media/au-woni/scenic.html) and as a potential water body of national importance for recreation by the Ministry for the Environment (http://www.mfe.govt.nz/publications/water/national-importance-jul04/html/page7.html).

The major recreational activities that take place on and in the lake include:

- Trout and coarse fishing
- Canoeing
- Rowing
- Dragon Boating
- Outrigging
- Sailing
- Windsurfing
- Kayaking
- Swimming
- Scuba Diving
- Radio Yachting (Quarry Lake)

No power boats are permitted on the lake other than rescue craft for boats training and competing on the lake.

A number of facilities, such as boat ramps, jetties, clubhouses and parking areas have been provided around the lake in both Council reserves and on public land. Areas of the lake have been designated for different activities, rowing, a canoe course, Waterwise and dragon boat training, most of which are out in the main area of the lake.

As mentioned previously, there are several parks along the lake edge and an esplanade walkway links three of the reserves on the northern shores to the primary school. The draft Reserve Management Plan for the Reserves Bordering Lake Pupuke (2004) proposes the extension of this walkway around the lake.

Table 2
Types of Recreational Areas within the Lake Pupuke catchment

Type of recreational reserve	Area (ha)	Percentage of Total Catchment
Recreation 1	13.0	15%
Recreation 2	2.0	2%
Recreation 3	0.2	0.2%
Recreation 4	1.0	1%

4 LAKE PUPUKE - EXISTING ENVIRONMENT

4.1 General Description of Lake Pupuke

Lake Pupuke is located to the north of the Waitemata Harbour, within the suburban areas of Milford and Takapuna, on Auckland's North Shore. The lake (centre) is located approximately at latitude 36°47.25'S, longitude 174°46.25'E (Department of Survey and Land Information NZMS 260 Sheet R11).

The full name in Maori for the lake is Pupuke Moana. This is a reference to the springs at Thorne Bay (named Wai Kokopu meaning 'water of the common eel'), where the discharge from the lake emerges through fissures in the underlying volcanic rock. The lake was also formerly known as Lake Takapuna.

Pupuke is a small but deep lake (57 metres deep) in relation to its surface area. It is roughly circular in shape with a total shoreline length of 4.5km and a surface area of 110 hectares. There are no inlet streams or surface outlets. An underground outlet runs out at Thorne Bay into the Hauraki Gulf. The hydraulic residence time (ie. the length of time taken for a parcel of water to pass through the lake and out to sea) is relatively long, about 30-40 years.

Basalt flows outcrop above water level in many places around the lake, and magnetic records confirm the existence of a continuous or nearly continuous shallow shelf of basalt around the lake. The margin of the lake is steeply cliffed and has been enlarged considerably by erosion of the crater walls by lake waters. The lake bottom starts to fall away sharply to its maximum depth about 9.1 metres from the lake edge in most places. Offshore the shelf is known to terminate abruptly in cliffs also, formed by the same layer of basalt which is at least 10m thick.

Lake Pupuke is a "warm monomictic" lake. This term refers to the mixing regime of a lake, which is driven primarily by wind and temperature and varies over the course of a year. For most of the year (from about mid-October to winter) the lake is thermally stratified. A less dense warm layer of water (the "epilimnion") lies over a cooler deep layer (the "hypolimnion"). The density difference between the two layers (the "metalimnion") is sufficient to effectively isolate the layers from each other so that there is very limited interchange of materials and processes between the layers. The part of the metalimnion which has the greatest rate of temperature change with depth is called the "thermocline". Over the 2002-03 and 2003-04 summers, Lake Pupuke's metalimnion remained steady and strong at about 20 metres depth, the hypolimnion was around 12.5^{o}C and the epilimnion increased to over 22^{o}C (NIWA, 2004). The stratified structure of such a lake persists until the surface layer cools sufficiently in winter for the two layers to approach the same temperature, when wind can again completely mix the lake.

As its catchment is low lying with no major topographical features, the lake is exposed to weather from all directions. The predominant wind direction is from the southwest (as for the rest of North Shore and Auckland). The lake is also periodically exposed to sea breezes from the northeast but is protected from winds off the open sea by Rangitoto. The lake has a fetch of

1025 metres (Holmes, 1994). These factors affect the limnology of the lake and the mixing of lake waters.

The North Shore City Council and the Auckland Regional Council have regulatory functions in respect of Lake Pupuke while the bed of the lake is vested in the Crown (and controlled by Land Information New Zealand (LINZ) on behalf of the Crown).

In addition to the recreational values discussed previously, the lake is known for it's wildlife values. Hochstetter first recorded these values in 1857. He reported seeing hundreds of wild-ducks were swimming on the lake, which was 'said to be abounding in all kinds of fish, especially eels'. Furthermore, 'on the shore we fished interesting fresh water shells and freshwater plants out of the water, and the wood furnished us many a beautiful fern'.

Today the lake has shallow margins, which provide areas for water weed and small areas of rushes and raupo. A good variety of waterfowl species occur, including black swan, mallard, grey duck, Australian coot and NZ scaup. Four species of shag may also be present. The lake has been classified as a Site of Special Wildlife Interest (SSWI) by the Department of Conservation, with a ranking of moderate to high.

4.2 Receiving Environment

At Thorne Bay, water from Lake Pupuke flows from cracks in basalt rocks and cascades through small pools to the sea.

The coastal receiving environment at Thorne Bay is characterised by an intertidal reef formed by lava flows from the Pupuke eruption. These lava flows contain one of the best examples in the world of a forest killed and fossilised by the passing volcanic material, with cylindrical moulds (up to 2 metres diameter) of hundreds of tree trunks. The area where the springs discharge is fairly localised and located to the end and just to the north of Minnehaha Avenue.

This coastal area lies within the adjoining East Coast Bays/Wairau Combined Drainage Catchment 2 and is described in Report KC119. The report observed that the hard substrate of the reef supports intertidal and shallow subtidal communities encompassing a diverse range of marine flora and fauna. At least 28 species of conspicuous marine invertebrates and algae have been noted along and adjacent to the reef.

4.3 Hydrology

4.3.1 Overview

Several researchers have investigated the hydrology of the lake in recent years, including the Auckland Regional Water Board in 1979, RA Hoare & Associates in 1990, Holmes in 1994 and Ladd in 1997. A brief overview of the current level of understanding is provided below, more detail can be found in the KC55 report and the Integrated Catchment Management Plan for the area (KC66).

The hydrology of Lake Pupuke is believed to be complicated due to the structure and function of underground outflow and catchment runoff input and these components are not completely understood at the present time.

Two-thirds of rainfall entering the lake falls directly upon it's surface, with the remainder entering via surface runoff from the catchment. Runoff from the catchment is believed to flow quickly to the lake without percolating through the ground, although there is some uncertainty regarding this due to the complex geology of the catchment. The lake is responsive to significant rainfall events, causing significant increases in lake water level over a short time.

There is not believed to be any salt water influence on the lake.

The average residence for water in the lake has been estimated at 30 years, and the time for water to flow from the lake to Thorne Bay is estimated to be less than one week.

Researchers have proposed that outflow from the lake to Thorne Bay is controlled by a sill or pipe with outflows not occurring when the lake level drops below it. Studies have indicated that outflow is greatest between 5.55 and 5.65 metres above mean sea level (mamsl), and is non-existent when lake levels are below 4.2mamsl. Therefore the outflow structure is likely to be present around these levels. There is anecdotal evidence that when lake levels were low due to water abstraction in the first half of the 20th century, witnesses saw water flowing into rock fissures at the north eastern end of the lake.

4.3.2 Water Abstraction

A significant period in Lake Pupuke's past is the nearly 50 years (1895–1943) during which time the lake was used as a domestic water supply, firstly to supply Devonport and later much of the North Shore as well.

Abstraction and the surrounding land uses had a significant impact on the Lake during this period. Over-abstraction and drought caused water levels in the lake to fall dramatically in 1914 and 1916, and concerns were raised that the lake would become contaminated by salt water if levels fell below sea level. Levels continued to fall until 1943 (the maximum amount the level is believed to have fallen from the natural level was eight metres), when a rapid rise was measured. It wasn't until 1965 that lake levels are believed to have returned to natural levels.

Since the 1960s, observations have indicated that the natural seasonal variation in lake level is in the order of 0.5 to 1 metre, with maximum levels dependent on rainfall in the preceding six months or so (Hoare, 1990).

In the 1920s and 1930s water quality was a serious problem in the lake, due to the surrounding land uses and lack of sewage treatment and various steps were taken to try and address this problem, including chlorination (1923), enactment of a bylaw to control surrounding land uses (1932), installation of a water purification plant (1933) and copper sulphate treatment to reduce algae levels (1934).

Lake Pupuke continued to supply water to the North Shore suburbs until in 1941 the Board of Health declared the lake closed as a public water supply. By December 1942 a new pipeline had been constructed to bring water from the Waitakere Ranges to the North Shore, running 15 miles from the Waitakere Filter Station via Hobsonville to Birkenhead and on to the lake pumping station. Pumping of the lake waters continued as a supplementary and emergency supply up until 1959, when pumping finally ceased entirely with the opening of the Harbour Bridge which brought with it a new water main across the harbour.

The lake today remains an emergency water source for a highly populated area with high civil defence importance, and was called in to play during the water crisis of 1994, with water taken by electric pump from the adjacent Quarry Lake for non-potable purposes. The public were permitted to draw water from the lake by bucket during the shortage, and the Council offered tanker deliveries of water to residences and businesses at a cost of $50.

4.4 Riparian Vegetation

Riparian vegetation provides a number of ecosystem services for lakes, such as:

a) Maintaining bank stability

b) Providing riparian and aquatic habitats

c) Reducing contaminant and nutrient inputs

d) Attenuating runoff

Section 4.12 (Physical Characteristic of the lake edge) and Figure LP-3 record the observations made of riparian vegetation extent during the boat shoreline survey on a reach by reach basis.

Overall, the lake edge is highly modified and there are few places around it where a natural lake to land vegetation transition occurs. A mixture of native and introduced plants occur, with plants managed and planted by residents in places. Some of the reserves bordering the lake support native woodland. A remnant stand of broadleaf forest in Sylvan Park on the northern edge of the lake has several fine stands of karaka and kohekohe, as well as puriri, taraire and kowhai. This area is identified as a “Priority Vegetation Site” in the North Shore Ecological Study.

The draft management plan for the reserves bordering the lake (2004) proposes further riparian planting around the lake edge to assist in reducing nutrient input to the lake and provide wildlife habitat for native species.

4.5 Wetlands

Larger wetlands on the North Shore have been identified as part of the North Shore Ecological Study and various other planning documents. During the boat survey of the Lake Pupuke perimeter, all wetlands above 4m were mapped and described. Although some of these wetlands may be small, they play an important role in providing flood attenuation, habitat areas, wildlife corridors and treatment for stormwater. Locations are shown on Figure LP-8.

In urban areas wetlands are often drained, modified or artificial. Generally, wetlands contain a diverse range of flora and fauna and offer significant habitat for many rare and threatened species. Wetlands are important storage areas for floodwaters, with swampy areas acting as sponges, soaking up water during heavy rain. Instead of the instant runoff that is typical of drained land, a swamp releases its water gradually over an extended period of time. Wetlands can also be useful for stripping sediments and other contaminants from discharges.

Drainage or modification of a wetland and clearance of nearby native vegetation will affect its biological and hydrological values. In urban areas wetlands are often drained or modified.

The following types of wetlands occur within the Auckland region:

e) Significant wetlands identified for their representative or biological diversity value, as defined in various planning documents

f) Palustrine – Permanent or ephemeral swamp or bogs with emergent vegetation

g) Lacustrine – Perimeter of lakes and open water bodies

h) Riverine wetlands – headwaters of ephemeral streams, floodplains of larger rivers and streams,

i) Sand dune - wetlands associated with sand dunes

j) Volcanic - wetlands associated with volcanic craters

k) Coastal - wetlands associated with coastal waters

l) Artificial - artificial wetlands

m) Other - other wetlands

4.5.1 Natural Wetlands

For the purpose of this document natural wetlands are those that would have occurred naturally as a consequence of the surrounding topography or geographical features in the area and were not created by man. These wetlands may be modified from their natural state by vegetation removal, introduction of exotic species, modification of banks and altered flow due to catchment development.

Five natural lake edge (lacustrine) wetlands were identified during the lake edge survey, and they are pictured and described below.

Natural Wetlands in the Lake Pupuke Catchment (Note: wetland areas are indicative only)

Eco-point: 1006-1007

Photocode: d31f53

Wetland Type: Lacustrine

Classification: Natural

Area in ha: 0.01

Description: Hollow stemmed reeds

Eco-point: 1010-1011

Photocode: d31f71

Wetland Type: Lacustrine

Classification: Natural

Area in ha: 0.08

Description: Emergent hollow stemmed reeds, flax

Eco-point: 1012-1013

Photocode: d31f90

Wetland Type: Lacustrine

Classification: Natural

Area in ha: 0.04

Description: Hollow stemmed reeds, flax

Eco-point: 1012-1013

Photocode: d31f91

Wetland Type: Lacustrine

Classification: Natural

Area in ha: 0.03

Description: Hollow stemmed reeds, flax

Eco-point: 1017-1001

Photocode: nil

Wetland Type: Lacustrine

Classification: Natural

Area in ha: 0.01

Description: Raupo wetland

4.5.2 Artificial Wetlands

Artificial wetlands have been constructed for a range of purposes, which can include construction for sediment removal, stock watering or historically for water supply.

Currently there are no artificial wetlands in the Pupuke catchment, however a wetland stormwater device is proposed in the southwest of the catchment, above Quarry Lake on Northcote Road Extension. The wetland will treat a total area of 1.4 hectares, which includes a small commercial area and a number of high use roads which access North Shore Hospital.

4.6 Aquatic Vegetation

The reports KC54 and KC116 provide detailed information about the aquatic flora of Lake Pupuke. Below is a summary of the key features.

4.6.1 Phytoplankton

Live microscopic plants (invisible to the naked eye except to give water a green colour) commonly known as algae or phytoplankton live within lake waters. They exist as single-celled forms, multicellular colonies and filaments and generally drift freely through water, carried by currents, although some can control their depth by altering their bouyancy.

Cyanobacteria (commonly called blue-green algae) are aquatic bacteria that can photosynthesise like algae. They are usually unicellular and often grow in colonies large enough to see. Between 25-50% of all cyanobacterial blooms are associated with toxin production and have been known to kill livestock, wildlife and humans.

Investigative work undertaken at Lake Pupuke by Cassie for the (now defunct) Department of Scientific and Industrial Research (DSIR), over 11 years from 1976-1987, identified 96 taxa of phytoplankton from 102 algal samples, including three potentially toxic blue-green algae. The blue-green algae, *Microcystis aeruginosa* was recorded as having bloomed every summer in the lake. An algal bloom of a non-toxic species (*Botryococcus braunii*) was also recorded in 1981.

Phytoplankton sampling data more recently obtained from the ARC, indicates that four species of potentially toxic blue-green algae have been found to be present in the lake since September 2001 (*Anabaena sp.*, *Aphanocapsa delicatissima*, *M. aeruginosa*, and *Oscillatoria sp.*).

Blooms of blue-green algae have occurred recently in Quarry Lake – in early January 2004 and again in January 2005. Members of the public were advised to remain clear of the water Quarry Lake until the blooms ceased.

4.6.2 Macrophytes

The following aquatic macrophytes occur in Lake Pupuke:

- Raupo (*Typha orientalis*)
- Papyrus
- Rushes and sedges (*Eleocharis and Scirpus*)
- Duck-weed (*Lemna* and *Spirodela*)
- *Salvinia* sp. (a free floating fern)
- *Azolla* sp. (a red floating water-fern)
- *Potamogeton* sp. (water-weed with pointed floating leaves)
- *Vallisneria gigantica* (introduced submerged eel grass which is extensive and very abundant around the edges of the lake)
- Oxygen weeds *Egeria densa, Elodea canadensis* and *Lagarosiphon major*
- Water milfoils (*Myriophyllum* spp.)
- *Chara* and *Nitella* (native species of branched algae – form meadows below the *Vallisneria* fringe)

The macrophyte community of Lake Pupuke is dominated by the introduced submerged adventive *Vallisneria gigantica*, also known as eel grass, ribbon weed and tape weed. This was deliberately planted in 1885 and became a nuisance within 10 years of its establishment, and has remained so ever since. Over 100 years later, *Vallisneria* is still the dominant and most abundant macrophyte in the lake (Coffey, 2003), and in combination with the introduced oxygen weed *Egeria densa* (likely to have originated from resident's fish bowls, water birds and boat introduction), completely covers the entire littoral range. Other introduced oxygen weed species that occur in the lake are *Elodea Canadensis* and *Lagarosiphon major*. All of these species are Class B weeds (i.e. not allowed to be distributed or sold).

Dislodged *Vallisneria gigantica* is very buoyant and floating rafts of the weed have become a nuisance to recreational users at the eastern end of the lake in particular. The decaying weed also impacts on water quality, odour and the aesthetic appeal of the lake.

Numerous and varying weed removal techniques have been attempted over the years. These have included hand harvesting, the use of a jet boat engine, drag lines, herbicides and during the late 1980s a 'Supersucker' was used to 'suck' weed from the lake. This was an 18-tonne truck incoporating a giant vacuum unit, the only one of it's kind in NZ. Weed was fed into 20 centimetre wide tubes and vacuumed into a 13 cubic metre tank. Any water taken up with the weed was pumped out. The NSCC Parks Department currently hand harvests "dead" floating weed on a response basis.

Recent studies have been undertaken to determine the best way to address the ongoing problems with *Vallisneria* and *Egeria* (see KC54 for more details). A way forward has yet to be agreed, and is complicated by confusion over which organisation is legally legal responsible for addressing the weed issues.

4.7 Invertebrates

A wide range of invertebrates have been found to populate the lake waters, including a variety of the native freshwater mussel (*Hyridella* sp.), a small freshwater crab *Hymenosoma lacustris*, which was apparently first discovered in Lake Pupuke and although was once well known there, is believed to be severely reduced or even extinct, and populations of the introduced freshwater Medusa jellyfish (*Craspedacusta*) which periodically occur in Quarry Lake.

Other types of invertebrates present in the lake include:

- Protozoa
- Rotifers
- Green and brown hydra (Cnidaria – related to jellyfish and anemones)
- Crustacea, including water fleas (Cladocera) and Copepods
- Freshwater snails (Mollusca) – four secies including the spined *Potamopyrgus antipodarum* forma *corolla* and *Gyraulus corinna*
- A species of freshwater limpet (*Ferrissia neozelandica)*
- Dragonflies and damselflies (Odonata)
- Beetles (Coleoptera)
- Caddisflies (Trichoptera) e.g. *Paroxyethira hendersoni*
- Pond moth (Lepidoptera) - *Hygraula nitens*
- Water bugs (Hemiptera) such as water boatmen, pond skaters, water measurers
- Flies (Diptera) such as midges and mosquitoes
- Oligochaete worms
- Flat worms (Turbellaria)

4.8 Birds

The birdlife of Lake Pupuke consists of a combination of species which breed at the lake, and others that use it as a feeding ground or refuge during the hunting season. The Department of Conservation has noted that a number of species of rare birds live both in and around the lake. Species which occur at the lake include:

- Black Swan
- Mallard duck
- Grey duck
- Canada geese

- Australian coot
- Pukeko
- NZ scaup
- Pied, little pied, black and little black shags
- White-faced & white herons
- Black-backed and red-billed gulls
- Fantails
- Welcome swallow
- Kingfisher
- Blackbirds
- Starlings
- Silver eyes
- Grey warblers
- Tuis
- Sparrows
- Chaffinches
- Green finches
- Yellowhammers
- White-fronted Tern
- Large Caspian Tern
- Bitterns
- Pied Stilts

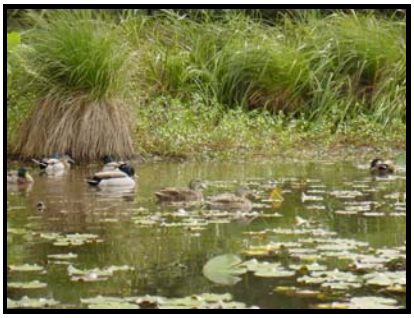
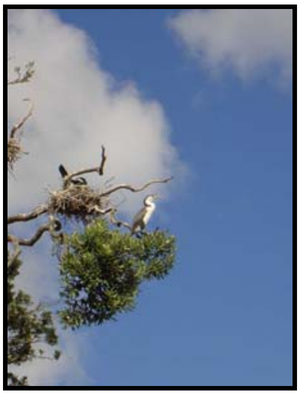
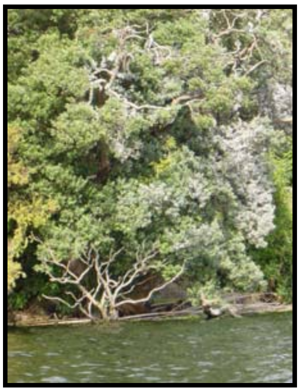
Eleven bird roosting sites were identified during the lake edge survey. Many of these sites are man-made structures such as boat ramps and pedestrian access areas. Their locations are shown on Figure LP-7.

The most significant roosting site is the shag colony along south-eastern side of the lake (site 11). The vegetation along this site is coated in guano and there are signs the pohutukawa trees holding the birds are suffering dieback – this may be a result of the large bird numbers or a natural process. There are many smaller sites which are feeding and sunning roots and do not play a major part in shag breeding.

White swans were a feature of the lake from the 1880s until sometime in the mid 1900s when they died out despite persistent efforts to maintain the population. The original swans were gifted by Queen Victoria to Sir George Grey, and migrated from Governor Grey's Kawau Island residence to the more preferable freshwater environment of Lake Pupuke.

Table 3
Observed bird roosting sites in Lake Pupuke

Site number	Comments
1	Grassed banks, mallard duck, black swan, pukeko
2	Waterfowl roosting site
3	Waterfowl roosting site
4	Pied shag roosting site 
5	Waterfowl roosting site, black swan
6	Waterfowl roosting
7	Waterfowl roosting
8	Pied shag roosting site 
9	Waterfowl roosting

Site number	Comments
	
10	Pied shag roosting site
11	Shag breeding site in pohutukawa trees  

4.9 Fish

The dominant fish populations of Lake Pupuke have changed considerably over time from a pre-European natural native fish population to a managed sports fishery. Today long and short fin eels are still present in the lake in large numbers and in a wide variety of sizes, suggesting that they are able to migrate to and from the sea to breed, possibly via the underground outlets to Thorne Bay, the stormwater system (if this is the case then the use of stormwater treatment devices such as Enviropods may become a barrier to migration), overland passage or via human introductions. The common bully is also still observed in the lake.

The lake has a long history as a trout fishery dating from the first liberations in the 1880s. With no tributaries suitable for spawning the trout population has been artificially maintained regularly since this time and until approximately 1967 trout stocks in the lake were considered good. Since then trout numbers have declined, and the lake has transformed into a coarse fishery, following the illicit introduction and success of a number of exotic species such as rudd, perch and tench. Koi carp have also been observed in the lake since the 1960s. Mosquitofish were introduced in the 1930s to control mosquitoes, and are now abundant, particularly in Quarry Lake.

Following is a list of species found in the lake today:

- Long and short fin eels
- Common bully
- Trout (brown, rainbow and brook)
- Tench
- Perch
- Rudd
- Mosquitofish
- Goldfish
- Catfish (liberated during the early 1900s)
- Koi carp

4.10 Surface Water Quality

Report KC53 provides a detailed summary of findings from water quality studies of Lake Pupuke undertaken between 1966 and 2004, and presents anecdotal information on water quality before 1966. This section provides a brief background on the key features of lake water quality in general, followed by a summary of the main points from the KC53 report to give an overview of the current level of understanding of water quality in Lake Pupuke.

4.10.1 Background

Dissolved oxygen

Aquatic ecosystems such as lakes and streams both produce and consume oxygen. Oxygen enters the water by diffusion from the surrounding air, aeration through the turbulent action of running water (not so applicable to lakes) and as a product of photosynthesis. Conversely, respiration by aquatic animals, decomposition and various chemical reactions consume oxygen. Dissolved oxygen concentrations can fall in nutrient rich waters due to increased biochemical oxygen demand (the consumption of oxygen by decomposing organic matter), through chemical oxidation and decomposition. As dissolved oxygen concentrations in water drop, aquatic life can be put under stress. The lower the concentration, the greater the stress, with organisms either having to move away or die.

Healthy aquatic environments generally have a dissolved oxygen saturation of between 80 and 100% and saturation values of >80% are utilised as an identifier of acceptable levels to support aquatic life.

Nutrients and eutrophication

Plants and algae require both nitrogen and phosphorus in order to grow. Phosphorus is usually the nutrient that limits productivity in most freshwater ecosystems (and this is the case for Lake Pupuke) because the available concentrations compared to the concentrations required by plants are generally lower than for nitrogen. Therefore if phosphorus concentrations are increased (even by only small amounts), this can cause tremendous increases in growth. The presence of phosphorus in lakes also enables plants to use other nutrients more efficiently, further increasing productivity.

Phosphorus is normally measured as total phosphorus and as the dissolved form. The latter is important as an available nutrient. However, total phosphorus does play a role in the pool of available nutrients for plant growth in freshwater.

Nitrogen is present in a variety of forms in freshwater. Dissolved forms of nitrogen include nitrate, nitrite and ammonia. The dissolved forms are important as sources of nutrients in waterways as their concentration has a direct effect on the growth of aquatic plants and periphyton. Ammonia is one of the key forms of dissolved organic nitrogen in waterways. At high concentrations ammonia can have a number of effects at the cellular level in organisms, including toxicity. The median ammonia level measured by the ARC was 0.05mg/l in Lake Pupuke. The mean measured in all streams by Project Care was 0.04mg/l.

Eutrophication is a natural process lakes gradually go through as they age. Sediment, silt, and organic matter gradually fill a lake, and increasing concentrations of nutrients stimulate the growth of aquatic plants and algae so the lake becomes more productive. Natural eutrophication occurs over hundreds or thousands of years. However human activities (particularly runoff or discharges from urban and agricultural areas containing sewage effluent, fertilizers and sediment) can greatly accelerate this process.

Throughout the eutrophication process the physical, chemical, and biological composition of a lake changes, and scientists have developed a classification system to describe each stage – or “trophic state”. Each trophic state indicates the lake’s general level of water clarity, nutrient enrichment, and algal and aquatic plant abundance. However, trophic state should not be considered a discrete category, but rather part of a continuous spectrum. “Oligotrophic lakes” have clear water, low nutrients concentrations and high dissolved oxygen concentrations throughout. At the opposite end of the trophic range are “eutrophic” lakes, which have high nutrient levels, high productivity, abundant aquatic plants and algae and decreased water clarity. “Mesotrophic” lakes fall between oligotrophic and eutrophic lakes.

Stratification and water quality

Section 4.1 introduced the concept of lake stratification. This feature of lake dynamics has important consequences for water quality. While the lake is stratified, the oxygen consumed during decomposition in the bottom layer (the hypolimnion) cannot be replaced by oxygen from the air and there is usually a steady depletion in the deep waters. Similarly the products released during decomposition, particularly plant nutrients, cannot reach the upper water where they could be used for plant growth. Thus over summer a situation often develops where a well-oxygenated, low nutrient layer of warm water overlies a nutrient-rich but oxygen depleted lower layer. When the lake becomes completely mixed in winter, nutrient and oxygen concentrations are more evenly distributed vertically.

4.10.2 Lake water quality prior to 1966

Little scientific data on water quality is available prior to 1966 – although there is much anecdotal information arising from the use of the lake as a water supply. As mentioned in Section 4.3.2, there was much concern over deteriorating lake water quality in the 1920s and 1930s. In 1921 the Department of Health was called in and warned that quality of water in the lake was deteriorating, with residents nicknaming the lake 'Poohpuke' due to the stench of the weeds growing at an alarming rate over the surface of the water. The weed growth and deterioration of the water became a source of many complaints that the water was undrinkable and the bath water was green with algae. In 1923 chlorinating equipment was installed and weed cutting undertaken.

By 1927 water quality was such a concern that a Water Commission of Enquiry into Lake Pupuke was set up. This found that of 62 houses and two cowsheds in the catchment, only seven houses were on septic tanks and five connected to the sewer – with wastewater from the cowsheds and remaining houses gaining ready access to the lake. A bylaw intended to protect the lake from contamination by the surrounding land area was enacted in 1932, and in summary, prevented wading, bathing or washing, a dog or other animal to enter the lake, or the keeping of horses within four chains (80 metres) of the edge of the lake, or a dog or pig within the catchment.

During the 1930s 'Pupuke water' became known for its vile taste and smell due to the presence of *Ceratium* algae, which emitted oil when chlorinated. A further water purification plant was installed in 1933 and a scheme to augment the lake supply with water from the Wairau Valley was investigated and recommended by Council. By January 1934, Devonport's Borough Engineer, Mr E Griffiths had finally found a solution for the 'protozoa problem', successfully treating the lake with copper sulphate.

4.10.3 Lake water quality from 1966-2004

Various water quality studies of the lake have been undertaken since 1966. Studies undertaken in the 1960s and 1970s concluded that the lake was eutrophic, with urban stormwater and emergency sewer overflows believed to be the causes of poor water quality. Decaying water weeds on the lake bed and shoreline and black swans feeding on *Vallisneria* were also believed to be increasing nutrient concentrations and organic loads. Water rights granted to sewage pumping stations in the late 1970s were expected to reduce overflows considerably and hence improve water quality.

In the 1980s, studies recorded the lake's nutrient status varyingly as eutrophic or mesotrophic. Vant and Pridmore (1990a&b) investigated changes in water quality in the period 1966 to 1990. This work indicated that water quality had improved over this period, consistent with a reduction in wastewater loads reaching the lake. Changes observed included:

- A decrease in phytoplankton abundance;
- Increased water clarity;

- Decreased consumption of oxygen in bottom water in summer; and
- A possible decrease in nitrate and ammonia concentrations.

For the period 1976-1990, short-term variations in water quality were observed but no long-term trends were apparent. The reports state that although enrichment had decreased, the lake waters in 1990 were still moderately fertile (mesotrophic – eutrophic) and could support nuisance blooms of blue-green algae if enriched.

NIWA undertook water quality sampling fortnightly in the period 1992-1996 for MfE's New Zealand Lakes Monitoring Programme (reported in NIWA, 1998). This study concluded that the lake was "mid range mesotrophic", and although the trophic status did not change and clarity increased over the period, phytoplankton concentrations increased and hence NIWA recommended that the lake be watched carefully.

Subsequent reports on the 1992-1996 data and more recent data collection (NIWA 1999, NIWA 2000 (TP 132), NIWA 2001 (TP150), NIWA 2002 (TP190), NIWA 2004) have found that:

- Of the seven lakes in the ARC Lakes Monitoring Programme, Lake Pupuke has the second highest water quality, and has clear water, low faecal coliforms (although in 2001 coliform levels were elevated) and low suspended solids concentrations;
- Water quality in the lake may be changing - most indicators suggest deteriorating water quality but increasing clarity, which is an unusual situation (although NIWA (2000) found that clarity decreased and NIWA (2004) suggested that water quality of the lake had not declined significantly between the mid-1980s and 2003/04) – observed changes may be part of a cyclical change in water quality;
- Much of the uncertainty around water quality trends is caused by the large number of missing values and imprecise records in the data set;
- The 1992-1998 data showed a strengthening of thermal stratification during summer due to regional warming, which reduced wind–induced mixing, and the period of stratification increased;
- NIWA (1999) suggested that the extent of anoxia, temperature, nutrient and suspended solids concentrations may be increasing in the bottom (hypolimnetic) waters – various potential causes of these patterns were suggested, including minor geothermal activity. In contrast, NIWA (2004) did not find significant differences between the oxygen depletion rates of the hypoliminion over summers 2002/03 and 2003/04 and the mid-1980s;
- Internal nutrient regeneration may be much greater than new inputs from the land via groundwater and surface run-off into the upper water column. However, with the very long residence time, these upper water column nutrients accumulate in the lake and eventually add to the nutrient regeneration in the following stratified period. When the lake mixes, these accumulated nutrients become available for algal growth and algal blooms develop in the lake (NIWA, 1999). Burns & Coffey

(2003) suggested that around 15% of phosphorus loads come from sources external to the lake such as stormwater, birds and rain.

4.11 Sediment Quality

No data on the sediment quality of the lake was identified in this study.

4.12 Physical Characteristics of the Lake Edge

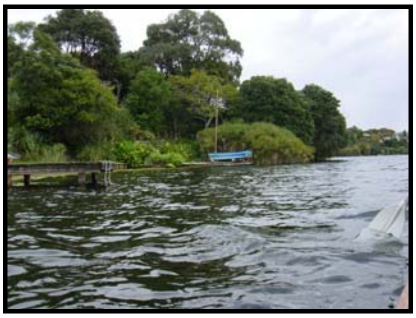
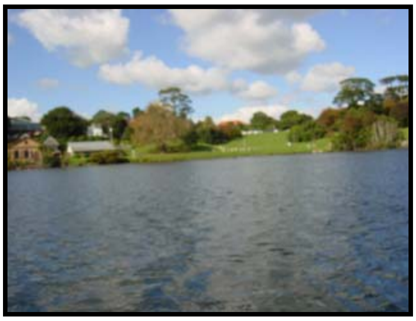
During the boat survey of the lake edge, the shoreline was divided into reaches of similar physical characteristics and these are shown on Figure LP-3. Table 4 summarises the key characteristics of each reach such as bank modifications, erosion, bank height, bank angle, riparian vegetation type and extent.

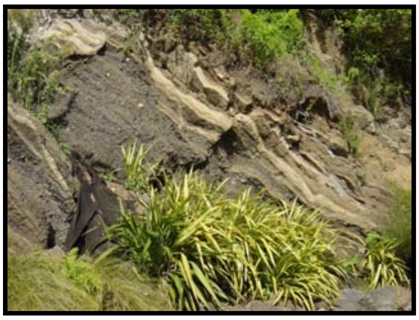
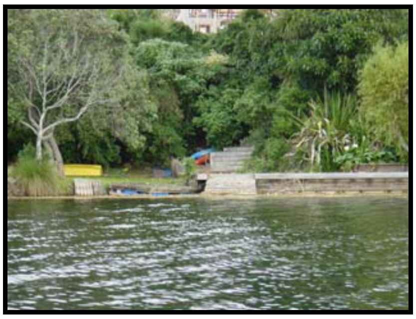
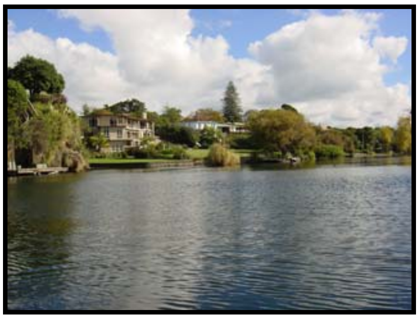
A number of engineering structures (all stormwater pipes discharging to the lake) were also identified, and the locations of these are shown on Drawing LP-6. Erosion at outfalls was not identified as an issue during the survey. A significant proportion of outfalls known to exist from historical information were not found and it is believed that many of these are now located below the current water level as a result of lake levels rising in the mid-1900s (refer Section 4.3).

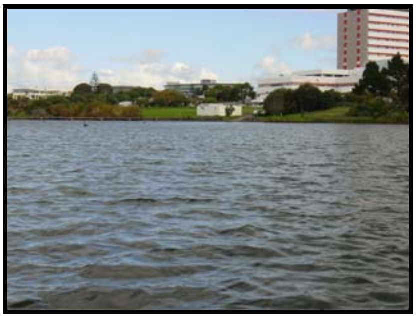
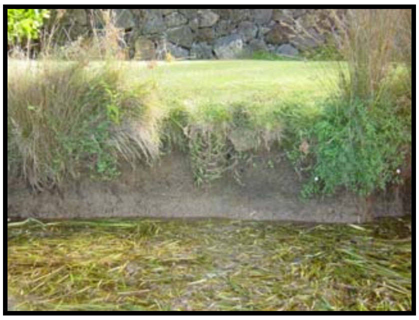
Overall, of the 4.3km of shoreline inspected, 5% showed signs of ‘slight’ erosion (9.5% of unlined banks). Forty-four percent of the banks were lined or reinforced. A relationship between bank lining and overhead cover of riparian vegetation was found – banks with greater than 50% lining had less than 10% overhead cover; and banks with less than 50% lining had an average of 40% overhead cover.

Table 4
Physical Details of the Lake Edge

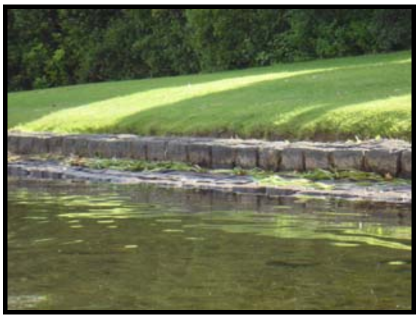
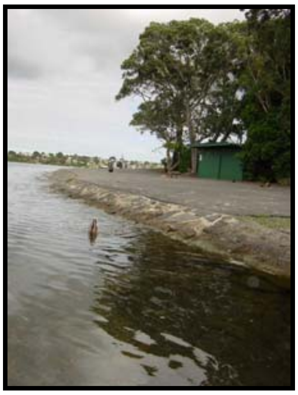
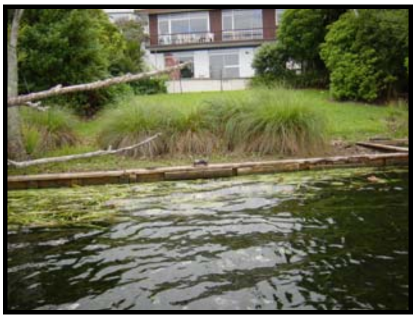
Reach No.	Summary of Physical Details
1017 - 1001	Length: 340m Modifications: 30% reinforced banks Bank height: 0. 3m Bank angle: 30^{o} Erosion: 10% Vegetation: Native canopy, mixed sub canopy and ground cover Lakeside vegetation cover: 30%

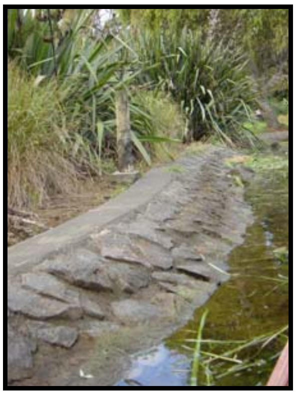
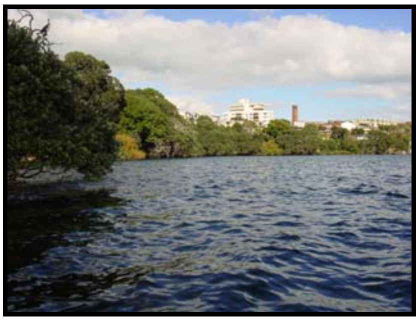
Reach No.	Summary of Physical Details
	
1001 – 1002	Length: 70m Modifications: 80% reinforcing Bank height: 0.8m Bank angle: 35° Erosion: 10% Vegetation: No canopy or sub canopy, just cut grass Lakeside vegetation cover: 0% 
1002 – 1003	Length: 78m Modifications: 80% reinforcing Bank height: 0.8m Bank angle: 35° Erosion: 20% Vegetation: No canopy or sub canopy, just cut grass Lakeside vegetation cover: 5%
1003 – 1004	Length: 167m Modifications: No modification, basalt rock Bank height: 0.8m Bank angle: 60° Erosion: 10% Vegetation: Native throughout reach Lakeside vegetation cover: 10%

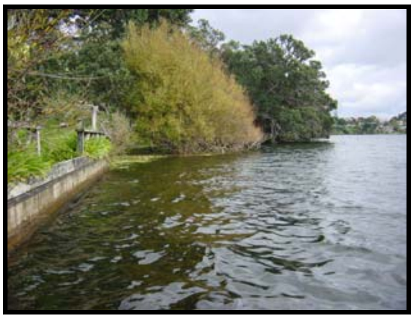
Reach No.	Summary of Physical Details
	
1004 – 1005	Length: 190m Modifications: 80% reinforcing, wood Bank height: 0.8m Bank angle: 60° Erosion: 0% Vegetation: Mixed throughout Lakeside vegetation cover: 10% 
1005 – 1006	Length: 360m Modifications: 80% rock wall lining Bank height: 0.8m Bank angle: 80° Erosion: 0% Vegetation: Mixed throughout Lakeside vegetation cover: 10% 

Reach No.	Summary of Physical Details
1006 – 1007	Length: 490m Modifications: 70% lined Bank height: 0.8m Bank angle: 70° Erosion: 0% Vegetation: Mixed to exotic throughout Lakeside vegetation cover: 5% 
1007 – 1008	Length: 310m Modifications: 60% lined 40% unlined Bank height: 0.6m Bank angle: 40° Erosion: 5% Vegetation: Exotic throughout Lakeside vegetation cover: 10%  
1008 – 1009	Length: 227m Modifications: Unlined Bank height: 0.3m Bank angle: 40° Erosion: 10% Vegetation: Exotic throughout Lakeside vegetation cover: 60%

Reach No.	Summary of Physical Details
1009 – 1010	Length: 115m Modifications: 100% lined Bank height: 0.5m Bank angle: 90° Erosion: 0% Vegetation: No canopy or sub canopy, just cut grass Lakeside vegetation cover: 0%
1010 – 1011	Length: 443m Modifications: Unlined Bank height: 0.3m Bank angle: 30° Erosion: 10% Vegetation: Native throughout Lakeside vegetation cover: 50% 
1011 – 1012	Length: 260m Modifications: 100% lined rock wall Bank height: 1m Bank angle: 90° Erosion: 0% Vegetation: No canopy or sub canopy, just cut grass or concrete Lakeside vegetation cover: 0%

Reach No.	Summary of Physical Details
	 
1012 – 1013	Length: 370m Modifications: 10% lined banks (wood) Bank height: 0.3m Bank angle: 10° Erosion: 10% Vegetation: Mixed throughout Lakeside vegetation cover: 20% 
1013 – 1014	Length: 135m Modifications: 100% lined rock wall Bank height: 0.3m Bank angle: 35° Erosion: 0% Vegetation: No canopy mixed sub canopy and ground cover Lakeside vegetation cover: 20%

Reach No.	Summary of Physical Details
	
1014 – 1015	Length: 100m Modifications: 100% lined banks Bank height: 0.8m Bank angle: 90° Erosion: 0% Vegetation: No canopy mixed sub canopy and ground cover Lakeside vegetation cover: 0%
1015 – 1016	Length: 565m Modifications: 10% reinforced banks Bank height: 0.3m Bank angle: 40° Erosion: 10% Vegetation: Native canopy mixed sub canopy and ground cover Lakeside vegetation cover: 30% 
1016 – 1017	Length: 144m Modifications: 30% reach reinforced banks Bank height: 0.4m Bank angle: 30° Erosion: 15%

Reach No.	Summary of Physical Details
	Vegetation: Native canopy mixed sub canopy and ground cover Lakeside vegetation cover: 35% 

4.13 Debris

4.13.1 Inorganic

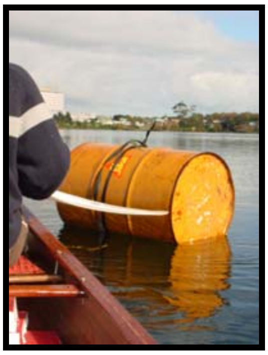
Litter and waste debris can clog inlets, catch basins, and outlets, lead to overflows, erosion and make stormwater devices ineffective in stormwater pollutant removal.

Discharge of stormwater containing debris results in aesthetic issues and can have ecological effects (such as the exposure of wildlife to plastic etc.)

A wide variety of debris is transported in urban stormwater. This arises as a consequence of human activities on and adjacent to roads and any area served by the stormwater systems.

This debris ranges from macro-sized objects that enter the stormwater system where grate access allows through to much smaller materials. Larger objects can be dumped directly into a water body.

The majority of inorganic debris observed during the lake survey consisted of plastic bags and general street litter, which enter through stormwater pipes (see left hand photo below). A 40-gallon drum was also observed and removed (see right hand photo below). Overall, insignificant amounts of inorganic debris were observed.

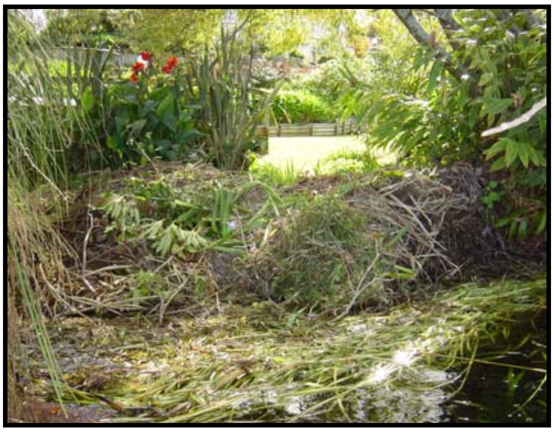


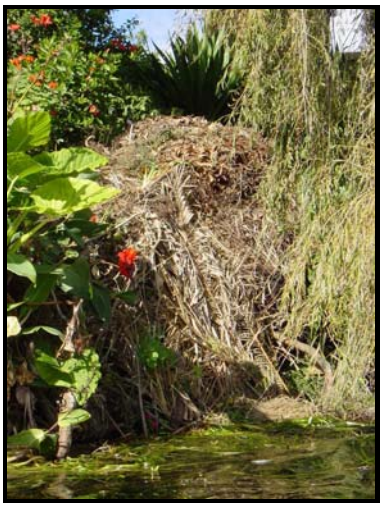
4.13.2 Organic

As part of the lake edge survey any organic material "dumps" (including compost heaps) were noted and photographed, as these are potential sources of nutrients and organic matter to the lake.

A total of six locations were identified as having organic "dumps". They were generally distributed around the Lake with a notable absence in the southern and southern western segments. This number was substantially less than originally anticipated. Many backyards were either very well kept or not kept at all. The well-kept properties often employ professional property maintenance companies to do the gardens and this organic material is thus possibly being taken off site.

Below are photos of several "dumps" or compost heaps observed near the lake edge during the survey.

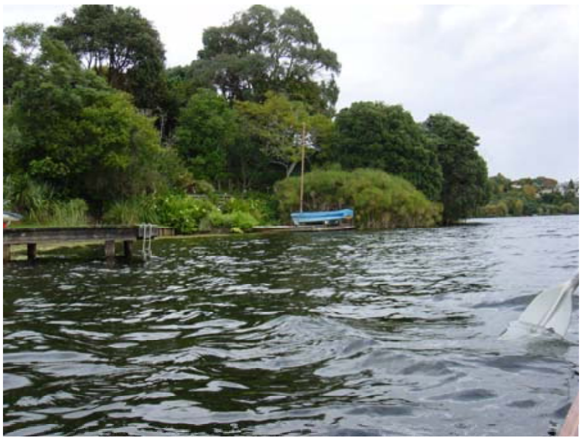


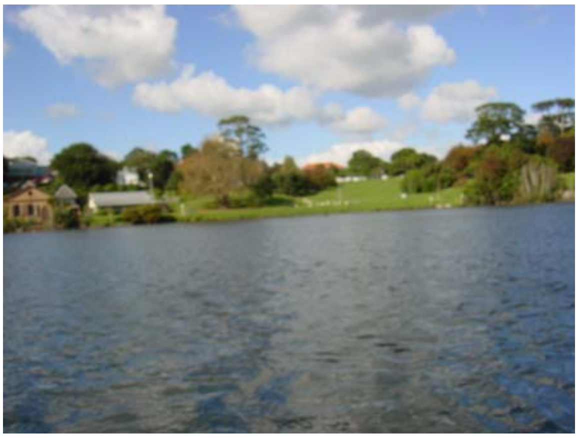


Appendix A

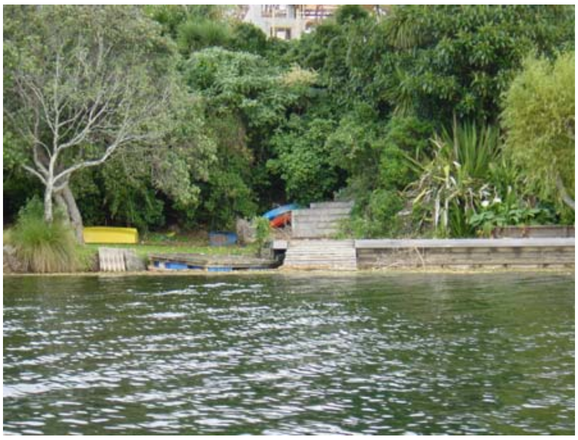
Representative Photos of Each Section of Lake Edge

(Eco Points Shown on Figure LP-8)


Eco 1001


Eco 1002


Eco 1004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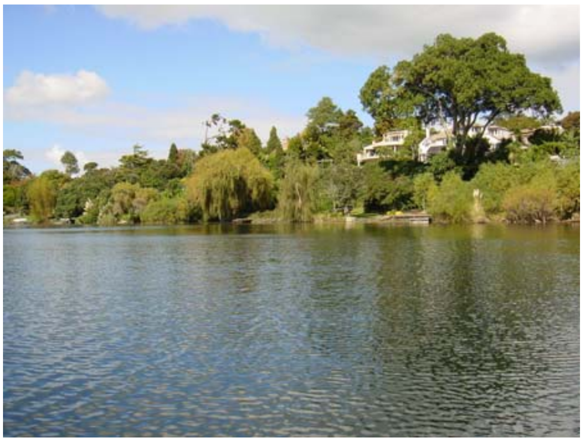
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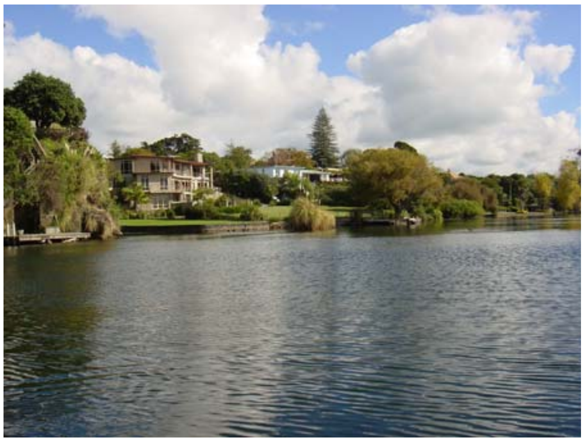
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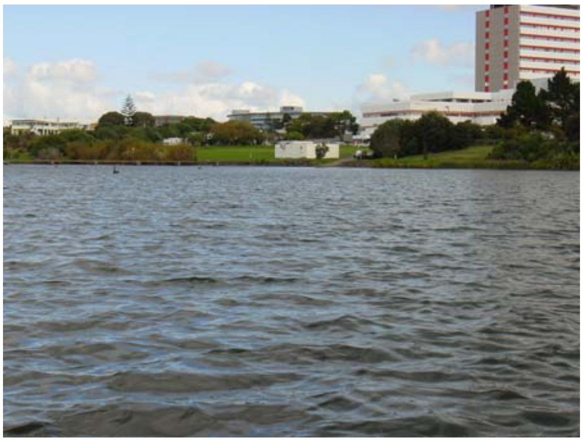
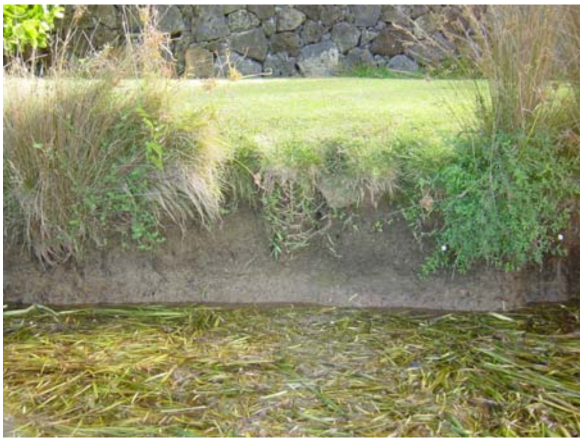


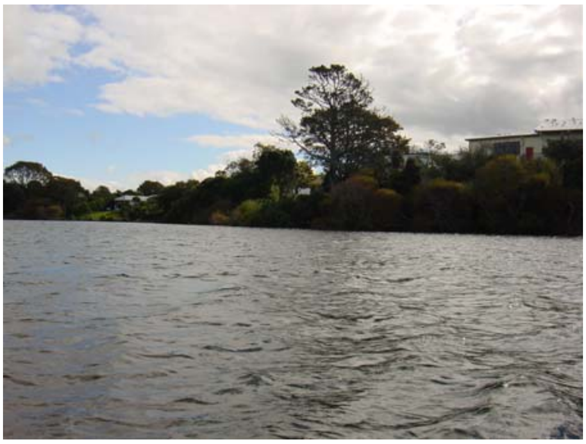
Eco 1007

Eco 1007



Eco 1008

Eco 1008



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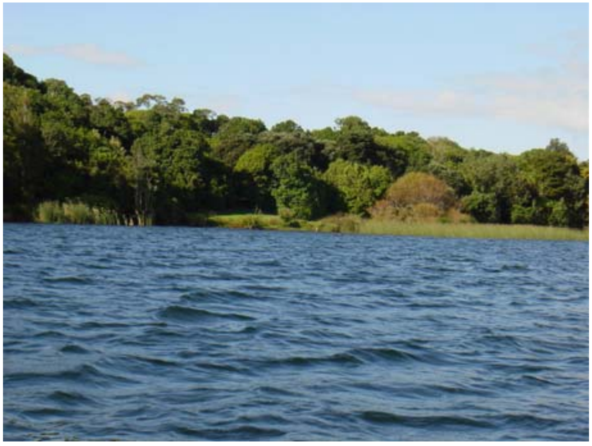
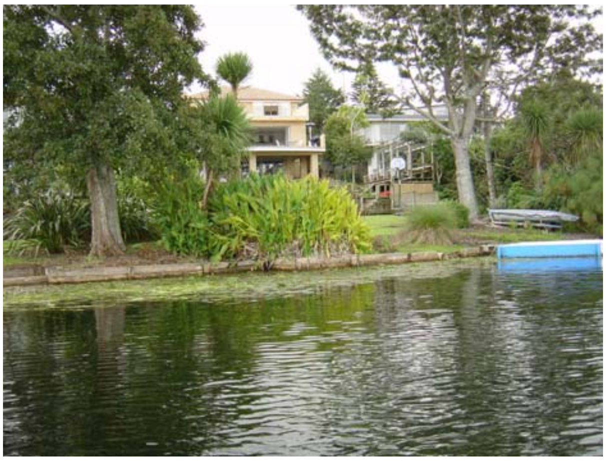
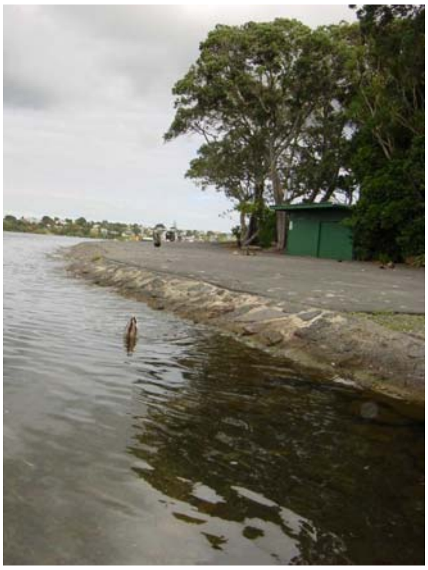


Eco 1011

Eco 1012

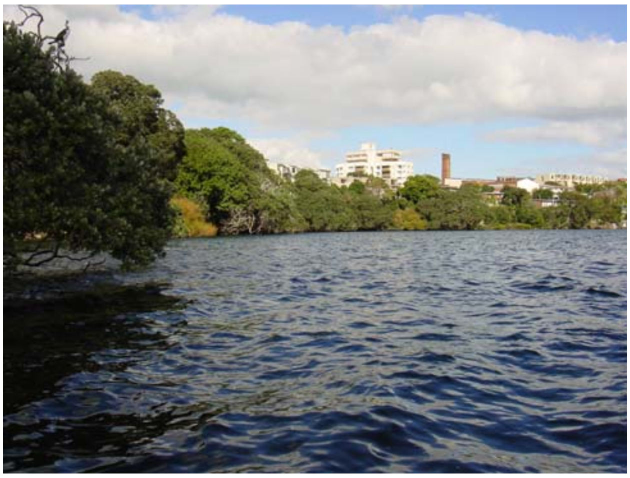


Eco 1013



Eco 1012

Eco 1014



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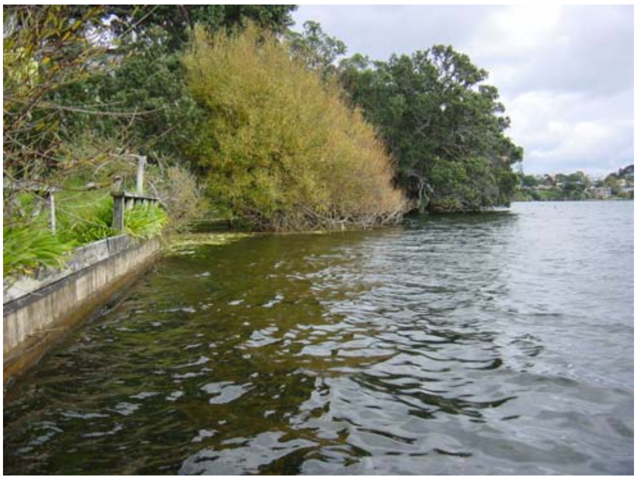

Eco 1017