SALT
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The Reservoir
Broad Scale Habitat Mapping 2019

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The Reservoir
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For the People
Mō ngā tāngata

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CONTENTS

TABLES

FIGURES

EXECUTIVE SUMMARY

BACKGROUND

This report summarises the results of broad scale habitat mapping of The Reservoir conducted on 8 March 2019. The Reservoir is a small shallow coastal freshwater lake in eastern Southland. It is one of several shallow lakes in Environment Southland's long-term State of the Environment (SoE) monitoring programme. The primary purpose of the 2019 survey was to determine whether there have been any substantive changes in aquatic macrophyte cover and species dominance compared with previous surveys, and to assess broad changes in previously mapped aquatic margin vegetation. The findings are compared with previous SoE studies and considered within the context of related investigations that have sought to understand the ecological health and potential drivers of degradation in Southland lakes.

KEY FINDINGS

The lake water body and aquatic margin of The Reservoir comprised an area of 48.5ha, of which the aquatic margin was very small (0.5ha) and dominated by the salt marsh rushes wiwi (*Juncus edgariae*) and *Carex secta*. There have been no substantive changes in marginal vegetation or lake macrophytes since the last broad scale survey in 2013. Eleven different macrophyte species were present in 2019, which was slightly greater than in 2013 and other surveys. Macrophytes occurred to varying extents across ca 37% of the lake body, with the deeper central lake area being bare. No macrophytes were found deeper than 2.9m, relative to a maximum lake depth of ca 6m.

When the total percent cover of macrophytes in different areas was accounted for, it was estimated that 23% of the total lake bed was vegetated, which is similar to estimates derived from earlier surveys where comparable methods were used. This coverage falls well short of the >50% cover recommended to ensure a clear water state. Macrophytes were dominated by blunt pondweed *Potamogeton ochreatu*s. Subdominant in the main body of the lake was the charophyte *Chara corallina*, which was most evident at depths exceeding 1m, probably reflecting the tolerance of this species to low light. The turfing *Glossostigma elatonoides* along with milfoil (*Myriophyllum* spp.), Horse's mane weed (*Ruppia polycarpa*), and occasional *Lilaeopsis ruthian*a were present in the shallow lake shore margin. Of the 23% macrophyte cover overall, 98% was attributable to native species, which was similar to the result from 2013. The only non-indigenous species recorded were Canadian pondweed *Elodea canadensis* and the water buttercup *Ranunculus trichophyllus*, both of which have been described previously from The Reservoir.

Overall, the limited areal coverage of macrophytes in The Reservoir likely reflects a combination of relatively deep water across much of the lake basin combined with moderate to poor water clarity, this restricting aquatic vegetation to the margins. High levels of nutrients and chl-a (an indicator of phytoplankton biomass) were evident from a cursory synthesis of water quality data, and likely reflect the combination of inputs from the primarily agricultural catchment, and the poor flushing characteristics of The Reservoir (i.e. a theoretical residence time of 55 days). The 2019 survey results do not suggest that The Reservoir has become further degraded in state from the assessments made previously. However, the results reaffirm previous findings that the lake is in moderate to poor ecological health and is vulnerable to further degradation.

RECOMMENDATIONS

Based on recommendations made in the present report and previous studies of The Reservoir, if ES intend to take actions to improve the state of The Reservoir, or at least minimise the risk of further degradation, we suggest that the following are considered:

- Develop appropriate nutrient load guidelines and limit total phosphorus input to the lake.
- Where feasible, take actions to improve water clarity to increase macrophyte cover to a target of >50%.
- Maintain or improve on the currently low level of non-indigenous macrophytes, including implementing actions to minimise the risk of new incursions.
- Continue the current water quality sampling programme and undertake an in-depth analysis of ES water quality data, to consider trends over time and potential explanatory variables.
- Undertake similar broad scale surveys at intervals of ca 5 years, in part to monitor macrophyte diversity and cover, but also to keep a check on the spread of establish non-indigenous macrophytes and the occurrence of new incursions.

Beyond these specific recommendations, if ES intend to take actions to maintain or improve the state of The Reservoir, and minimise the risk of degradation, we emphasise the importance of defining appropriate management objectives. This will help to define and optimise a long-term monitoring programme accordingly, in order to track changes in the state of the lake, and the effectiveness of any management initiatives. The design of any such monitoring programme should target the key stressors on the lake, and identify the data needs, methods, resolution and frequency required to detect changes in catchment pressures and responses in lake ecology within a time frame appropriate for effective management.

It is recommended that a desktop review of the current long-term sampling design be conducted prior to undertaking any further broad scale habitat monitoring, incorporating key lake attributes and supporting monitoring indicators that Environment Southland are currently developing.

1. INTRODUCTION

1.1 BACKGROUND

Environment Southland (ES) has a State of the Environment (SoE) monitoring programme to assess the ecological health of the region's coastal and estuarine systems, which includes several shallow coastal lakes. ES's interest in the health of these lakes reflects that they are often poorly flushed, and are in highly modified catchments whose primary land use is agriculture. As such, the lakes are both sensitive and susceptible to a range of associated stressors such as described in Table 1.

To manage lake health, ES require robust information on the impact of these stressors. This includes knowledge of intensification or changes in catchment land use, modification of lake margin habitat, altered drainage or flow conditions, and inputs of non-point source contaminants. Of particular concern are eutrophication from nutrient enrichment, and effects from fine-sediment input such as smothering of lake-bed habitat and increased water turbidity, which may in turn result in the loss of submerged macrophytes. Submerged macrophytes are important structuring elements in shallow lakes due to their ability to maintain high water clarity, which may markedly affect lake environmental conditions (Kelly et al. 2013). Shallow lake studies from overseas indicate that submerged macrophyte cover needs to be >50% to ensure a clear water state (Jeppesen et al. 1994, Kosten et al. 2009, Tatrai et al. 2009, Blindow et al. 2002, cited in Robertson & Stevens 2013a).

Charophyte dominated vegetation represents the optimum state for most shallow lakes because species in this group enhance water clarity and reduce phytoplankton growth. This effect is caused by processes such as sediment trapping and reduced sediment resuspension (Van den Berg et al. 1998), and efficient nutrient immobilisation within charophyte meadows (Blindow 1992; Kufel & Kufel 2002). Also, because charophytes are heavily calcified and rarely grow to the water surface in lakes deeper than 1m, they seldom interfere with boating and swimming activities. Many charophyte species also remain green in winter and therefore possibly cause less oxygen depletion during winter than annual submerged plants (Robertson & Stevens 2013a).

Submerged macrophyte losses related to nutrient enrichment generally result from the shading of plants by phytoplankton blooms, epiphytic overgrowth, or excessive growth of tall macrophytes. These mechanisms cause light limitation of plants and their ultimate collapse, in a process termed 'flipping' (Schallenberg & Sorrell 2009), which in some cases can be difficult to reverse, as the internal loading of nutrients from sediments and re-suspension of lake bed materials stabilise the new turbid-phytoplankton dominated state.

Because of the strong connection between intensified catchment land use and increased sediment and nutrient inputs, maintenance of a clear-water state for macrophyte dominated shallow lakes is commonly used as a measure to assess shallow lake health and the success of management initiatives. This focus reflects that the loss of aquatic macrophytes and the important ecological functions they fulfil, and development of a lake ecosystem dominated by phytoplankton and susceptible to algal blooms and water quality degradation, is an undesirable outcome.

1.2 SHALLOW COASTAL LAKE MONITORING

To date, the ecological status of six Southland coastal lakes has been assessed as part of SoE monitoring conducted between 2009 and 2014, namely Lake George, Lake Vincent, Lake Brunton, The Reservoir, Waiau Lagoon and Waituna Lagoon (Stevens & Robertson 2012; Robertson & Stevens 2013a, b, c, d; Burton et al. 2015). Additionally, in recent years ES has undertaken regular (typically monthly) surface water quality monitoring at many lakes and has also undertaken one-off bathymetric surveys. The aims of the past assessments have been varied, but in essence have sought to broadly determine the ecological status of each lake, and changes over time. Several related studies have utilised the Lake Submerged Plant Indicators (LakeSPI) method (e.g. Clayton & Edwards 2006) to assess the ecological condition of lakes in Southland or more broadly (e.g. Burton et al. 2015). The method is based on the assumption that native plant species and high plant diversity represent a healthier lake or better lake condition, while invasive plants are ranked for undesirability based on their displacement potential and degree of measured ecological impact. However, Robertson and Stevens (2013a) noted limitations in the use of the LakeSPI sampling methodology in shallow coastal lakes, and recommended broad scale mapping to provide a more comprehensive spatial assessment of submerged macrophytes and aquatic margin habitat.

1.3 PURPOSE AND SCOPE OF THIS REPORT

As part of ES's ongoing monitoring programme, Salt Ecology was contracted to undertake follow-

Table 1. Summary of key stressors affecting shallow coastal lakes in Southland. Modified from Stevens and Robertson (2012).

	Key Ecological Stressors Affecting Shallow Coastal Lakes
Sedimentation	Because shallow lakes are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays. In the last 150 years, with catchment clearance, wetland drainage, and land development for agriculture and settlements, many NZ shallow systems have begun to infill rapidly. Today, average sedimentation rates in our shallow lakes are typically 10 times or more higher than before humans arrived. The input of catchment-derived fine sediments can smother lake bed habitats, increase water turbidity, and lead to shading and loss of ecologically important aquatic macrophytes.
Eutrophication (Nutrients)	Excessive nutrient enrichment of shallow lake ecosystems, particularly with phosphorus and to a lesser extent nitrogen, stimulates the production and abundance of fast-growing algae, such as phytoplankton and short-lived macroalgae (e.g. filamentous species), at the expense of rooted aquatic macrophytes. Maintenance of a healthy aquatic macrophyte community in shallow lakes is beneficial to overall ecosystem health, and the presence of macrophytes has been shown to be important for modifying nutrient concentrations and reducing the potential for algal blooms. Nutrient thresholds required to maintain macrophyte growth in shallow lakes are difficult to predict, as the response depends on site-specific variables such as depth, substrate type (particularly mud content), humic content, wind exposure, water residence time, and water column mixing. However, at high nutrient concentrations, submersed macrophytes may be absent and a lake can become phytoplankton dominated.
Toxic Contamination	In the last 60 years, New Zealand has seen a huge range of synthetic chemicals introduced to lakes through land runoff, industrial discharges and air pollution. Many of them are toxic in minute concentrations. Of particular concern are polycyclic aromatic hydrocarbons (PAHs), trace metals, polychlorinated biphenyls (PCBs), and pesticides. These chemicals collect in sediments and may accumulate in fish and shellfish, potentially causing risks to humans and freshwater life. While the above contaminants are a particular issue in urban catchments, lakes in agricultural and horticultural catchments may also be exposed to compounds such as biocides and various trace metals (e.g. cadmium and zinc derived from fertiliser use).
Habitat Loss	Shallow lakes support many different habitat types including macrophyte beds, emergent aquatic plants (rushlands, herbfields, reedlands etc.), forested wetlands, shellfish, and a wide variety of substrate types ranging from unconsolidated cobble, gravel, sand, and mud to stable bedrock. The continued health and biodiversity of shallow lake systems depends on the maintenance of high-quality habitat. Loss of habitat and habitat diversity negatively affects fisheries, animal populations, filtering of water pollutants, and the ability of shorelines to resist storm-related erosion. Within NZ, habitat degradation or loss is common place with the major causes cited as human pressures on margins, drainage, reclamation, pest and weed invasion, reduced flows (damming and irrigation), over-fishing, polluted runoff, wastewater discharges, and excessive nutrient and sediment inputs.
Invasive species	Historic introductions of non-indigenous plants and animals, either accidental or deliberate, have led to a range of negative effects on the values of shallow lakes. Ecological effects include loss of biodiversity, changes in the composition of ecological communities, and functional changes to recipient ecosystems. In addition, more direct impacts on people can arise, such as loss of amenity value and physical interference with commercial activities (e.g. clogging of hydropower station intakes). In shallow lakes around NZ many internationally notorious plant and animal pests are already established, such as the macrophytes *Lagarosiphon major* and *Elodea canadensis*; however, some of the more remote and isolated lakes still remain free of such invaders.

up broad scale synoptic surveys of five previously sampled lakes (Lake George, Lake Vincent, Lake Brunton, The Reservoir, Waiau Lagoon) in summer 2019. The surveys were restricted in scope compared with the earlier SoE studies; their primary purpose was to undertake broad scale mapping of submerged and emergent aquatic macrophytes to determine whether there have been any substantive changes in macrophyte cover and species dominance compared with previous surveys, and to assess broad changes in previously mapped aquatic margin vegetation. This report summarises the results of a survey of The Reservoir (Fig. 1) conducted on 8 March 2019. Results are directly compared to earlier studies by Robertson and Stevens (2013a) and Burton et al. (2015), and are considered within the context of related investigations that have sought to understand the ecological health and potential drivers of degradation in Southland lakes (e.g. Schallenberg & Kelly 2012; Kelly et al. 2013; Kelly et al. 2016).

2. BACKGROUND TO THE RESERVOIR

Robertson and Stevens (2013a) provide background information on The Reservoir, which in turn reflects a summary by Schallenberg and Kelly (2012), although some of the summary data (e.g. lake depth and area) differ between the two studies. An overview of this background is paraphrased or repeated verbatim in the text below, and updated with information from more recent studies.

The Reservoir is a small shallow lake (48ha, ca 5.5m deep) situated 250m from Haldane Beach in eastern Southland between the Haldane Estuary and Porpoise Bay. The lake was formed from the damming of a small coastal creek, the outlet of which is now located at the southwest end of the lake. The lake outlet is not regulated and drains to the lower reaches of Haldane Estuary. The headwaters of the lake's catchment are indigenous forest, but the lake's small catchment (560ha) is dominated by intensive agriculture including dairying (Fig. 1). The lake is bordered by sand-dunes to the south. Although some of Southland's coastal lakes have an intermittent connection to the sea, The Reservoir is approximately 13m above sea level and therefore not subject to seawater intrusion. The small catchment results in a relatively low freshwater inflow to the lake and consequently a relatively long theoretical water residence time of 55 days, meaning that in-lake processes have some influence on water quality and ecology (Schallenberg & Kelly 2012).

Schallenberg and Kelly (2012) considered The Reservoir to be of ecological importance due to the presence of native macrophytes, high water clarity, high native fish abundance (including the presence of giant kokopu), and absence of non-indigenous fish species. However, at the time of their survey, Schallenberg and Kelly noted that The Reservoir was eutrophic due to a high phytoplankton biomass, and that macrophyte beds were sparse. They considered it among the most vulnerable of Southland's shallow lakes to further degradation and flipping.

More recently, Burton et al. (2015) applied the LakeSPI tool to The Reservoir in 2014, and categorised it as being in 'high' ecological condition (second from top in a five point scale) with a LakeSPI Index value of 67% (i.e. meaning the lake is at 67% of its maximum potential). This score reflected the limited presence of invasive macrophytes, with Canadian pondweed *Elodea canadensis* and the water buttercup *Ranunculus trichophyllus* present in low coverage at two of five sites surveyed.

Kelly et al. (2016) subsequently compared lake condition for four surveys at The Reservoir (2004 to 2013) using a four point ecological integrity index that accounts for water quality and native fish attributes in addition to macrophytes. The lake was assessed as being in the middle two scoring categories ('good' and 'fair') for most of the constituent metrics, but one year was rated as 'unacceptable' due to a low cover

The Reservoir has an extensively modified catchment with pastural grazing extending to the water edge in most places. Note emergent macrophytes growing to the water surface in the foreground, and small areas of rushland.

Figure 1. Location of The Reservoir

of native macrophytes (19% in 2013). Overall, Kelly et al. (2016) concluded that The Reservoir was in moderate to poor ecological health relative to other shallow lakes nationwide.

3. METHODS

3.1 GENERAL APPROACH

The March 2019 broad scale survey was undertaken by three Salt Ecology staff, supported by a local boat and skipper (Chris Owen, Southern Waterways). All sampling was undertaken from the boat or by wading along the lake margins. While the survey focus was on delineating the spatial extent, cover and dominant species present within the aquatic macrophyte community, a limited point-in-time assessment was also made of some key field measures of water quality, and samples were collected for sediment quality analysis. Terrestrial margin and emergent vegetation were additionally mapped from aerial photographs, to provide a coarse-resolution comparison with the 2013 survey.

The study focused on some key indicators of lake ecological health (Table 2), and a comparison of those indicators (where data were available) with the 2013 survey and other regional or national studies that have included The Reservoir. Most of these indicators relate to the trophic state of the lake system. For example, as described by Robertson and Stevens (2013a), nutrient-poor oligotrophic shallow lakes are likely to have the entire lake sediment surface covered by macrophytes, in particular charophytes. A more diverse assemblage (including milfoils, pondweeds, turf plants, and emergent plants) develops as the level of enrichment increases. Once nutrients reach eutrophic levels however, shallow lakes are characterised by a reduction in macrophyte

Table 2. Shallow lake ecological health indicators assessed in the 2019 survey.

Attribute	Rationale
Macrophytes	
Total lake bed cover	Shallow lakes with low nutrient status (oligotrophic and mesotrophic) may have the entire lake bed covered by macrophytes, with the cover decreasing as a lake becomes increasingly nutrient enriched and eutrophic.
Assemblage species richness and composition	Macrophytes in shallow lakes with low nutrient status will often be dominated by a cover of charophytes, and change to a more diverse and productive community as the level of enrichment rises, including milfoils, pondweeds, turf plants, and emergent plants. As enrichment increases, epiphytic plants may become more prevalent and macrophyte abundance may decline.
Maximum colonisation depth	The depth at which macrophytes grow may be restricted by increasing water turbidity (resulting from fine sediments and/or phytoplankton) and hence decreased light penetration for photosynthesis. Hence, maximum colonisation depth (MCD) is potentially a simple proxy measure of macrophyte abundance in deeper lakes, although this metric is only useful in shallow lakes if the MCD is less than the bottom depth.
Geographic origin	The occurrence of non-indigenous macrophyte species is a threat to a lake's ecosystem. The richness and cover of native vs invasive non-indigenous macrophytes is a simple indicator of a lake's 'nativeness'.
Water and sediment quality	
Secchi depth visibility	Field indicator of water clarity and potential for light penetration into the water column.
Water column chlorophyll-a (chl-a)	Field measure that provides a proxy indicator for phytoplankton biomass.
aRPD (apparent Redox Potential Discontinuity) depth	A subjective measure of the enrichment state of sediments according to the depth of visual transition between oxygenated surface sediments and deeper deoxygenated sediments (characterised by a change from lighter coloured to darker grey/black sediments).
Water and sediment nutrients	Total nitrogen (TN) and total phosphorus (TP) concentrations help to characterise the trophic status of shallow lakes.
Sediment total organic carbon	Indicator or organic matter accumulation in the sediment.
Sediment trace metals and metalloids	Indicators of trace contaminant inputs from catchment sources.

species richness, the development of bare areas, an eventual decline in macrophyte growth to low levels or a complete absence, and an accompanying increase in nutrients and phytoplankton. Some New Zealand studies have provided threshold levels for chl-a, nutrients and water clarity that are linked to the level of enrichment and a lake's trophic state (Burns et al. 1999, Burns et al. 2000, NPS-FW 2014).

3.2 FIELD-BASED MACROPHYTE AND SEDIMENT ASSESSMENT

Macrophyte data were collected by zig-zagging in a boat along eight cross-lake transects, with each transect positioned approximately 200m apart (Fig. 2). At specific stations along each transect (see Fig. 2), the following was conducted:

1. A camera attached to a surface monitor was slowly lowered to the lake bed and each macrophyte species present and its estimated percent cover were recorded.
2. Simultaneous with the camera drop, a custom-built sampling hoe on a telescopic pole (extendable to 6m) was used to collect macrophytes and associated sediment. The sampler had a 20x20cm flat bottom, two 20cm high enclosed sides and a supported open back. The front section, which digs into the sediments, was pointed. At deeper sites an Ekman spring-jawed box corer with surface trigger was deployed to sample bottom sediments (see photo). Typically, three samples were collected while the boat drifted during each camera drop. Based on the three samples combined:
    a. Sediment type was classified into predefined categories (Appendix 1).
    b. The depth of the apparent redox potential discontinuity (aRPD) layer was recorded If visible (see description in Table 2).
    c. The estimated relative prevalence of different macrophyte species was used as a proxy for their percent cover using categories in Fig. 3 as a guide.
    d. Representative photographs were taken.
3. Camera and macrophyte sample data were combined to provide a single percent cover value for each species at each sampling station, which reflected the consensus of two observers.
4. Water depth was recorded using a combination of boat depth sounder and sounding pole.

Sampling stations were selected on the basis of transition boundaries in macrophyte species or prevalence identified during the 2013 survey, with a particular focus being to identify any areas where macrophyte boundaries (between presence and absence) had expanded or contracted in the latest survey. Sample station data were recorded electronically in a template that was custom-built using Fulcrumapp software (www.fulcrumapp.com). Pre-specified constraints on data entry (e.g. with respect to data type, minimum or maximum values) ensured that the risk of erroneous data recording was minimised. Each sampling record created in Fulcrum generated a GPS position for that record.

In addition to the detailed assessment described for each sampling station, the camera and hoe method were also used at intermediate points, and the estimated macrophyte cover for each species at each point was recorded directly onto laminated A3 maps of the lake. Where emergent vegetation was visible, the approximate boundaries were drawn onto the map.

Ekman grab for sampling sediment in deep water

3.3 WATER AND SEDIMENT QUALITY

Water and sediment sampling were conducted at each of six stations: B3, D3, F3, G3 and H3 (see Fig. 2). Quantitative water quality measurements were made in situ using a YSI Pro10 multimeter (pH, dissolved oxygen, temperature, salinity) and a Delrin Cyclops-7F fluorometer with chlorophyll optics and Databank datalogger. These measurements were made ~20cm below the water surface, and ~20cm above the sediment surface, with care taken not to disturb bottom sediments before sampling. The thermocline depth, represented by abrupt changes

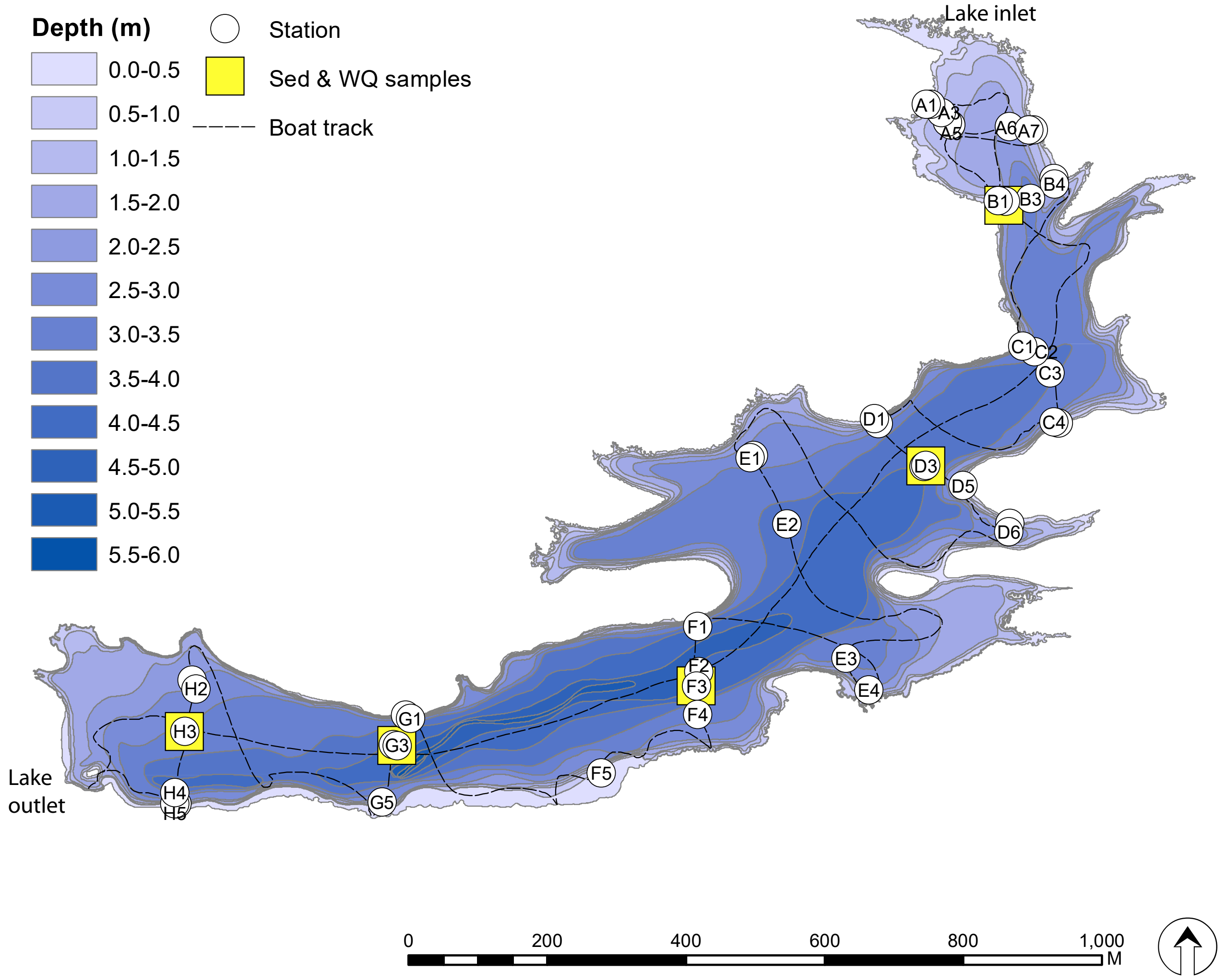

Figure 2. Sampling transects and stations where detailed assessment was undertaken. Water quality and sediment measurements were made at the five stations marked with yellow squares, with an additional water quality station at C3. Depth bands were compiled from data provided by ES and Thompson (2016).

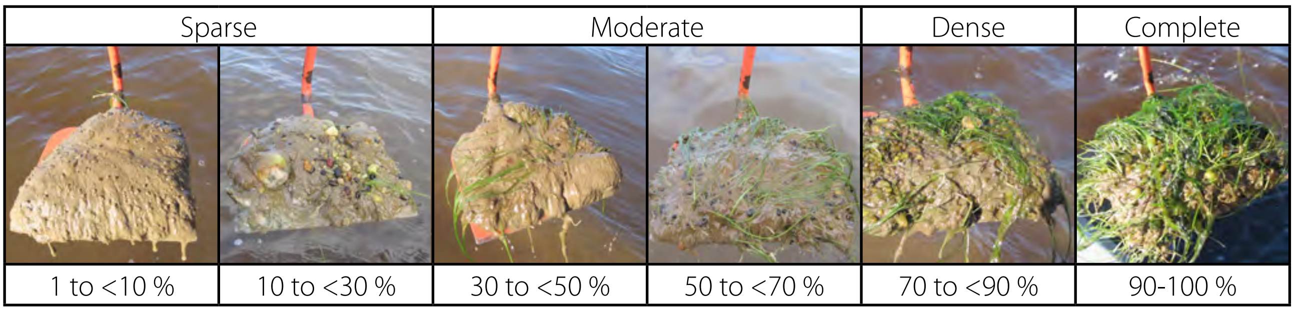

Figure 3. Visual rating scale for percentage cover estimates.

in temperature, was recorded if present. A modified secchi method was used to obtain a rough field estimate of water clarity. To supplement the synoptic field assessment of water quality, a summary was made of water quality data collected in 2000, 2004 and 2012 (reported in Schallenberg & Kelly 2012), again during the broad scale mapping in 2013, and subsequently by ES from two sites in the lake between March 2013 and June 2019. The ES data included a greater suite of water quality variables, such as nutrients, but not all are reported here. For comparison with the field meter salinity data collected in 2019, conductivity data (units mS/cm) reported in previous studies or in the ES dataset were converted to an approximate salinity value using the formula: salinity = [conductivity^1.0878]*0.4665.

At five of the six stations from where synoptic water quality measurements were made, three sediment subsamples were collected (to ~20mm depth) and composited into a single sample (~250g). The samples were generally taken from the hoe, but to obtain undisturbed sediments from the deepest sections of the lake a box corer was used. Samples were stored chilled or frozen and sent to a laboratory (RJ Hill Laboratories) for analysis of: particle grain size in three categories (% mud <63µm, sand <2mm to ≥63µm, gravel ≥2mm); organic matter (total organic carbon, TOC); nutrients (total nitrogen, TN; total phosphorus, TP); and trace metals or metalloids (cadmium, Cd; chromium, Cr; copper, Cu; lead, Pb; nickel, Ni; zinc, Zn; mercury, Hg; arsenic, As). Details of laboratory methods and detection limits are provided in Appendix 2.

3.4 DATA, QA/QC, MAPPING AND ANALYSIS

The lake mapping approach was based on the broad scale habitat methods described in the National Estuary Monitoring Protocol, that has previously been applied to Southland coastal lakes and lagoons (e.g. Stevens & Robertson 2012). Broad scale habitat features visible on aerial photographs were digitised into ArcMap 10.6 shapefiles using a Wacom Cintiq21UX drawing tablet, and combined with field notes on the laminated aerials, and georeferenced Fulcrum data and photographs to produce habitat maps showing dominant substrata and macrophytes. Macrophyte data are expressed in two ways

i. The percent of the lake body with ≥1% macrophyte cover, grouped based on defined bands of percent cover (e.g. Fig. 3). This reflects the overall spatial area within the lake where macrophytes were growing regardless of plant density, and replicates the approach of Robertson and Stevens (2013a).

ii. Total weighted % macrophyte cover. This reflects the total area of macrophyte cover within the lake incorporating plant density and area. It is calculated by: Sum (cover estimate x area)/total lake area x 100. It replicates the approach taken by Schallenberg and Kelly (2012) and was used with the raw data (Appendix 3) to calculate the percent cover of selected dominant species.

Following the field survey, sediment samples sent to RJ Hill were tracked using standard Chain of Custody forms, and results were transferred electronically to avoid transcription errors. Fulcrum field data were exported to Excel, together with data from the sediment analyses. To minimise the risk of subsequent data manipulation errors, Excel sheets for the different data types were imported into the software R 3.5.3 (R Core Team 2019) or into ArcMap, for analysis as described below. To ensure accurate and consistent outputs across the surveys, standardised coding methods in R and ArcMap were used for producing data summaries. For the mapping data, a suite of GIS scripts ensured attributes were consistently named, geometries were valid, and there was no duplication, gaps or overlaps in digitising.

For trace metals, sediment concentrations were interpreted in relation to ANZG (2018) sediment quality guidelines. The Default Guideline Value (DGV) and Guideline Value-High (GV-high) specified in ANZG are thresholds that can be interpreted as reflecting the potential for 'possible' or 'probable' ecological effects, respectively. Until recently, these thresholds were referred to as Interim Sediment Quality Guideline low (ISQG-low) and Interim Sediment Quality Guideline high (ISQG-high) values, respectively.

3.5 COMPARISONS WITH PREVIOUS STUDIES

Previous studies against which we compare the 2019 data (in particular for water quality and macrophytes), and use as context for explaining our key findings, were as follows:

- 2000: March 2000 synoptic water quality data collected by ES and summarised by Schallenberg and Kelly (2012).
- 2004: March 2004 synoptic water quality, macrophyte, plankton, invertebrate and fish data, described by Drake et al. (2011), with data summarised by Schallenberg and Kelly (2012).
- 2012: March 2012 synoptic water quality, macrophyte, plankton and invertebrate data collected by Schallenberg and Kelly (2012).
- 2013: February 2013 synoptic water quality and

macrophyte data collected using broad scale methods and reported in Robertson and Stevens (2013a).

- 2014: November 2014 synoptic LakeSPI assessment of macrophytes reported in Burton et al. (2015).
- 2013-2019 ES water quality data (see Table 4).

4. KEY FINDINGS

4.1 LAKE DEPTH CHARACTERISTICS

The ES depth profiling survey (see Fig. 2) shows that most of the lake area exceeds 1m in depth and has a maximum lake depth of ca. 6m.

4.2 LAKE SEDIMENTS

4.2.1 Sediment type

Based on the subjective classification of sediment type, an estimated 64% of the lake bed (31ha) consisted primarily of soft sandy mud sediments, with the remaining 36% being classified as muddy sand (Fig 4). Sediments with a sand dominant component were restricted to the western end of the lake, and in particular the southwest margin adjacent to the coastal sand dunes. The quantitative laboratory analyses revealed that composite sediment samples taken from the five locations were generally dominated by the sand fraction (Table 3, Fig. 5). Spatial patterns in sample data were consistent with the subjective classifications in that the mud content was greatest (46-49%) at the two stations (B3, D3) at the eastern (inlet) end of The Reservoir, and least (29-34%) at western stations F3, G3 and H3 (Fig. 4).

4.2.2 Sediment enrichment and contaminants

Sediments from all five stations had very high levels of total nitrogen (TN), total phosphorous (TP), and total organic carbon (TOC), probably reflecting a combination of root mass or detrital material from macrophytes, and catchment inputs (Table 3). Assessment of aRPD was moderately useful as an indicator of enrichment status, ranging from 1-5mm at the five sediment sampling stations. At other locations where aRPD was randomly checked it ranged from 0mm (i.e. black anoxic sediment at the surface) in areas of very soft mud to > 150mm (i.e. clean sediment) in areas of firm muddy sand. The most enriched locations may have corresponded to areas where there was localised accumulation of fine sediment and degradation of organic matter. Although this indicator may not be suitable in freshwater systems, for reasons described by

Pale brown oxygenated mud overlying black anoxic mud from site G3 in the central southwestern basin

Robertson and Stevens (2013a), it appeared quite reliable at The Reservoir. At 35 stations where aRPD was assessed, reliable assessment of aRPD could be made for all but four of them.

Trace metal and metalloid levels were low in all samples, and in all cases less that ANZG Default Guideline Values for 'possible' ecological effects. Hence, despite evidence from other regions that agriculture and horticulture can lead to soil contamination with trace metals due to land use practices such as fertiliser application (Gaw et al. 2006; Lebrun et al. 2019), these results strongly suggest that there are no significant sources of such contaminants in The Reservoir's predominantly agricultural catchment. It is possible that other types of trace contaminants could be present (e.g. agricultural biocides); however, a comprehensive assessment in this respect was not part of the present focus.

4.3 LAKE WATER QUALITY

Readily available water quality data are summarised in Table 4. The Reservoir waters are well oxygenated and well mixed, with no water column stratification present at the time of the survey, which is consistent with 2013 (Robertson & Stevens 2013a). Schallenberg and Kelly (2012) alluded to the potential for late summer stratification and bottom-water anoxia to develop in The Reservoir, but such an event does not appear to have been reported to date. The lake water is brown humic-stained and water clarity appears moderate to poor. A secchi range of 1.1-1.7m was measured in March 2019, which is within the narrow long term range measured by ES (0.9-2.2m, mean ca 1.4m).

As a measure of phytoplankton biomass, chl-a values were high at the time of the survey, and notably higher in the bottom water (19.5-56mg/m^3) than the

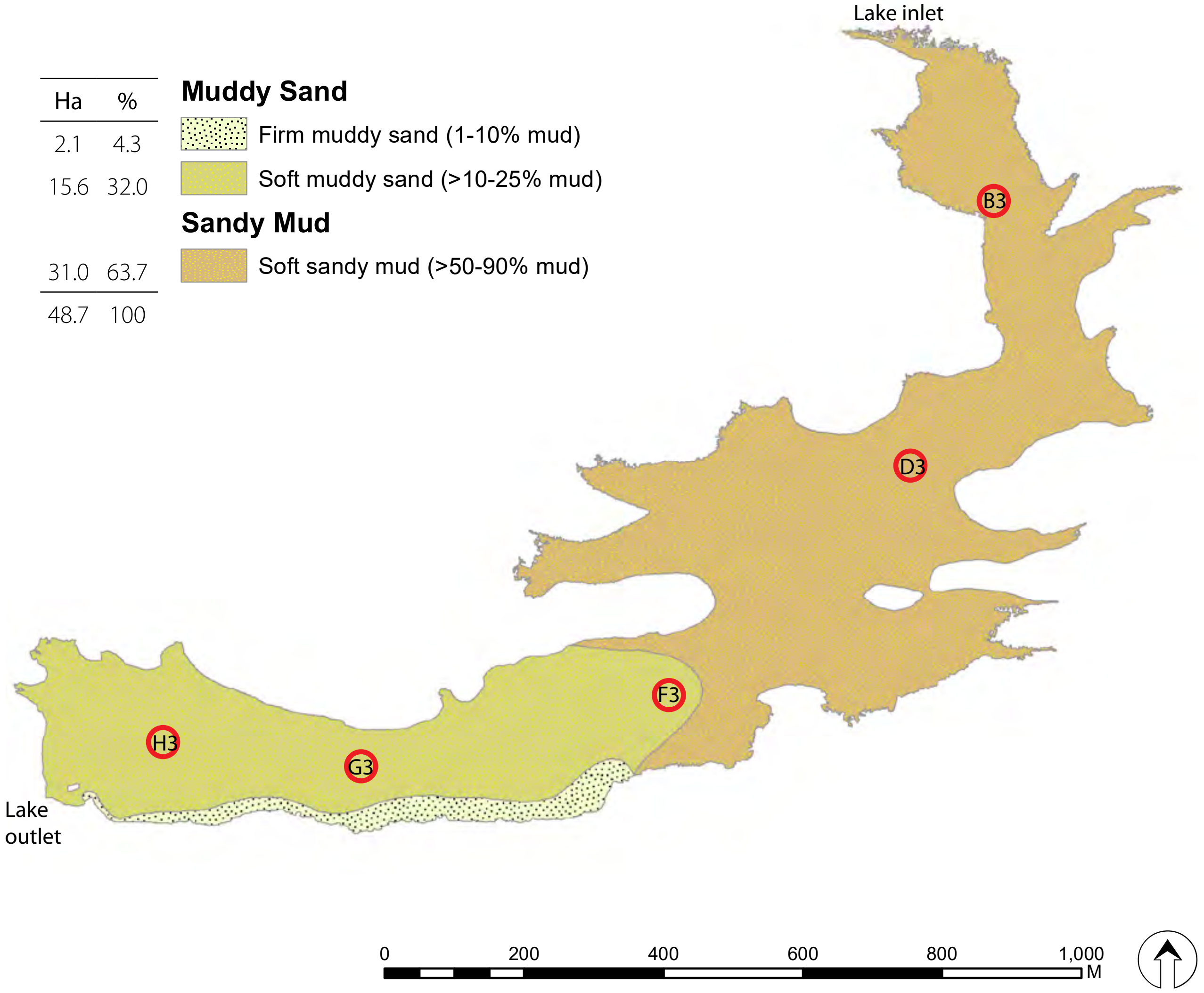

Figure 4. Substratum map and summary statistics of The Reservoir sediment classes. Percentages shown are of the total lake area of 49ha. Sites marked show sediment sample locations (see Table 3).

Table 3. Sediment sample analyses based on composite samples from each of five sampling stations at The Reservoir (see Fig. 4 for locations). Grain size classes as described for Fig. 5. Trace contaminants compared to ANZG (2018) sediment quality guideline values (see note 1)

Station	Mud	Sand	Gravel	aRPD	TOC	TN	TP	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
	%	%	%	mm	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
B3	45.6	54.4	<0.1	5	9.1	5400	850	3.4	0.172	15.9	12.7	0.10	8.0	8.8	69
D3	48.8	51.2	<0.1	1	7.9	5700	1020	5.5	0.137	19.4	12.0	0.11	8.8	11.2	57
F3	29.2	70.2	0.5	1	9.9	7600	1290	8.1	0.173	21.0	14.2	0.12	9.0	11.7	63
G3	33.9	66.1	<0.1	1	9.2	8000	1320	7.6	0.162	21.0	14.0	0.11	9.2	11.6	63
H3	30.8	69.2	<0.1	5	10.5	8500	1530	7.1	0.220	23.0	16.1	0.14	10.2	14.3	71
							ANZG DGV	20	1.5	80	65	0.15	21	50	200
							ANZG GV-high	70	10	370	270	1	52	220	410

Note 1. Brown shading represents contaminants whose concentration was less than half of the Default Guideline Value (DGV) for possible ecological effects

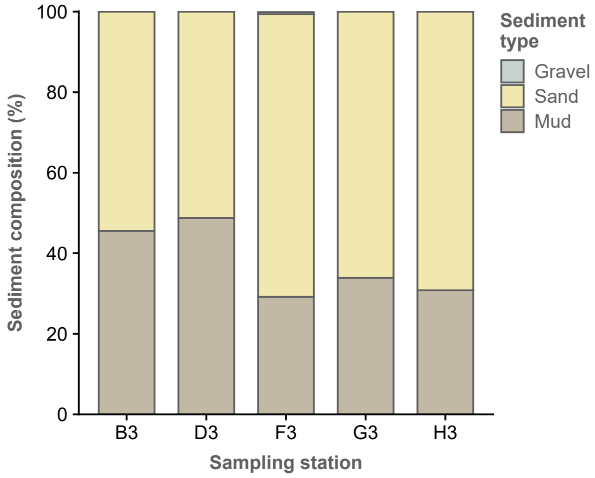

Figure 5. Sediment grain size based on composite samples from each of five sampling stations at The Reservoir. Grain size is classified into three broad categories: mud <63 µm (i.e. silt and clay); sand 63µm to ≤2 mm; and gravel >2 mm.

Brown humic stained water at the southwestern end of the lake

surface. Surface water values (5.5-10mg/m^3) were within the range recorded during ES monitoring (2.5-37mg/m^3). These elevated chl-a levels suggest excessive phytoplankton biomass, and are consistent with the low water clarity. Ignoring the outliers, the chl-a levels in Table 4 reflect highly enriched 'eutrophic' conditions, according to classification thresholds developed for New Zealand lakes (Burns et al. 1999; Burns et al. 2000).

Nutrient (TN and TP) concentrations measured by ES were also relatively high (see Table 4) and are indicative of quite high nutrient enrichment, which will be a key factor in the development of excessive phytoplankton biomass. Applying the NPS-FW (2014 nutrient thresholds, The Reservoir would be classified as eutrophic and at times hypertropic (i.e. extremely eutrophic) with respect to TN and TP.

Guidance criteria (NPS-FW 2014) indicate that median water column concentrations of TN, TP and chl-a fall largely within" Band C" (ecological communities moderately impacted by additional phytoplankton and macroalgae arising from elevated nutrients levels, with the cover and diversity of native macrophytes likely to be low). Maximum values indicate that at times The Reservoir falls into "Band D" (a high risk of excessive algal growth and likelihood of undergoing a regime shift to a persistent, degraded state without macrophyte/seagrass cover).

Given these indicators of water column enrichment, it would be of value to undertake a more in-depth analysis of the water quality data, to consider trends over time and potential explanatory variables.

Table 4. Water quality summary for The Reservoir comparing various parameters across different years. Data sources are described in Section 3.5. Where multiple values are summarised, the standard error (SE) of the mean and relevant sample size (n) are indicated.

Analyte	2000 (March)	2004 (March)	2012 (March)	2013 (Feb) Surface Range	2013 (Feb) Bottom Range	2019 (March) Surface (0.2m) n	Range	Mean	SE	2019 (March) Bottom (2.7-4.4m) n	Range	Mean	SE	ES data March 2013 - June 2019 Surface n	Range	Mean	SE
Chl-a (mg/m^3)	5.0	10.3	20.0	-	-	6	5.5-10	7.9	0.80	6	19.5-56	29.4	5.78	100	2.5-37	11.2	0.63
DO (g/m^3)	-	-	-	110-122	110-119	6	89.4-112	99.2	3.63	6	86-100.1	91.4	1.96	95	81.6-128	99.0	0.53
DO (%saturation)	-	-	-	11.7-12.0	11.1-11.7	6	8.85-10.59	9.54	0.27	6	8.49-9.73	8.92	0.18	95	7.34-15.6	10.8	0.13
pH	7.70	-	-	-	-	6	8.02-8.17	8.1	0.02	6	8.01-8.14	8.1	0.02	100	7.1-7.7	7.5	0.01
Salinity (psu)	-	0.10	0.12	0.12-0.12	0.12-0.12	6	0.1-0.14	0.13	0.01	6	0.13-0.14	0.14	0.00	95	0.1-1.36	0.1	0.01
Secchi (m, vertical)	-	-	-	-	-	-	-	-	-	-	-	-	-	11	1-1.75	1.4	0.08
Secchi (m, horiz)	-	1.00	-	0.85-0.9	-	6	1.1-1.7	1.35	0.09	-	-	-	-	81	0.9-2.2	1.4	0.04
Temperature (^{O}C)	-	-	-	16.0-16.5	16.0-16.1	6	15.7-17.2	16.7	0.22	6	15.6-16.7	15.9	0.18	95	4-20.9	12.0	0.46
TN (g/m^3)	0.925	0.615	0.630	-	-	-	-	-	-	-	-	-	-	100	0.44-0.78	0.6	0.01
TP (g/m^3)	0.046	0.021	0.036	-	-	-	-	-	-	-	-	-	-	100	0.016-0.085	0.0	0.00
TSS (g/m^3)	-	-	-	-	-	-	-	-	-	-	-	-	-	72	2.7-11	5.2	0.23
Turbidity (NTU)	-	-	11.5	-	-	-	-	-	-	-	-	-	-	26	0-4.4	1.9	0.25

4.4 LAKE VEGETATION

4.4.1 Terrestrial margin

The 200m terrestrial margin comprised an area of 130ha (Fig. 6). This margin was highly modified, being dominated by pastoral grassland (ca 79%). Small patches of scrub/forest (ca 10%) and flax (ca 6%) were also present, primarily to the southeast. The lake margins to the east have been largely fenced to exclude livestock and planted with riparian vegetation. The coastal dunes were vegetated with predominantly *Ammophila arenaria* (marram grass) and *Lupinus arboreus* (tree lupin).

Fringing rushland in the northern end of the lake

LCDB Class (Terrestrial Margin)		Ha	%
40	High Producing Exotic Grassland	80.3	62.0
41	Low Producing Grassland	22.1	17.1
43	Tall Tussock Grassland	0	0.3
45	Herbaceous Freshwater Vegetation	1.2	0.9
47	Flaxland	8.3	6.4
51	Gorse and/or Broom	2.5	1.9
54	Broadleaved Indigenous Hardwoods	13.2	10.2
71	Exotic Forest	1.7	1.3
		130	100

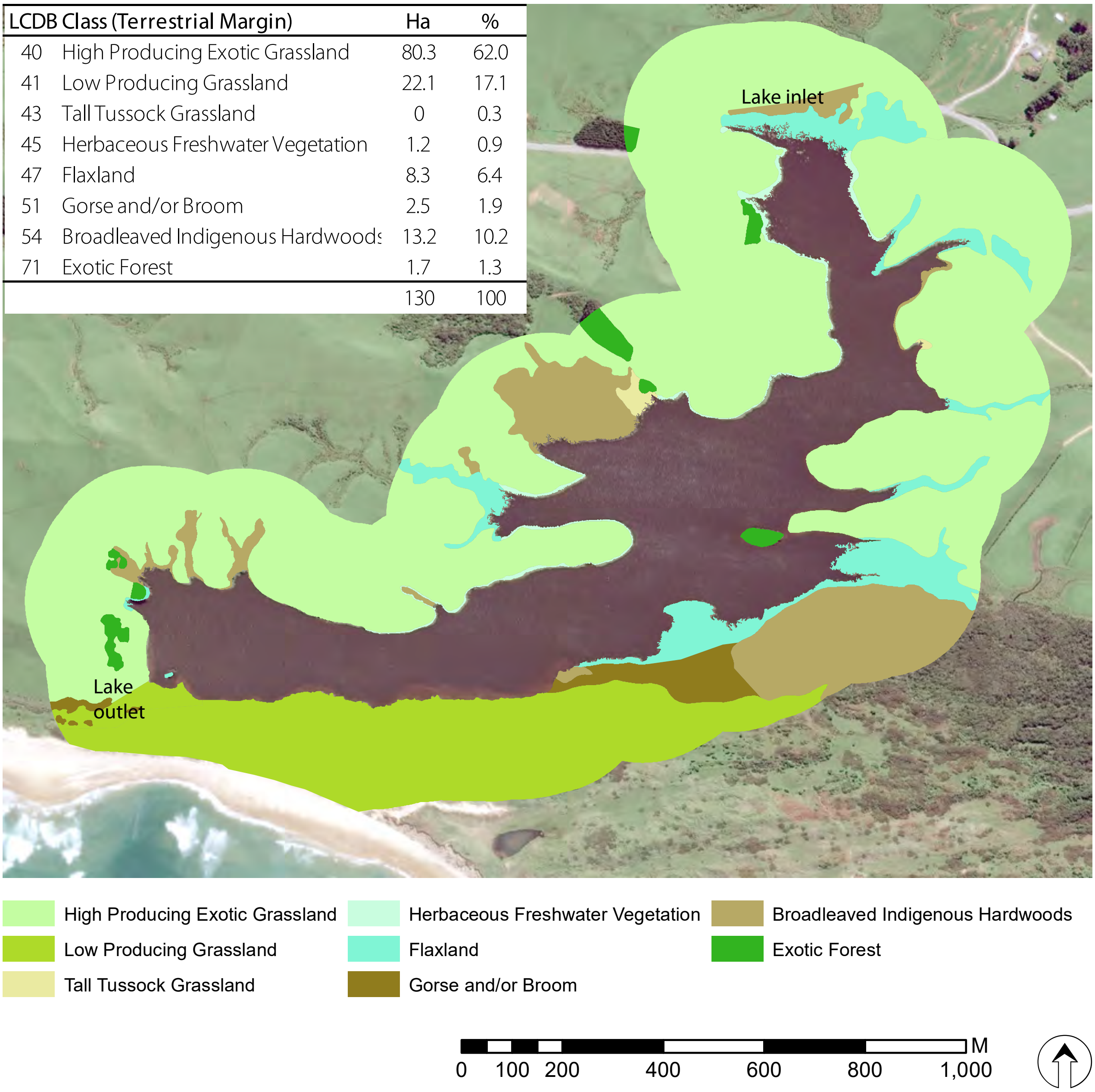

Figure 6. Landuse map and summary statistics for the 200m terrestrial margin of The Reservoir based on LCDB cover classes. Percentages shown are of the total terrestrial margin area of 130ha.

4.4.2 Lake aquatic margin and macrophytes

The lake water body comprised an area of 48ha, with the marginal vegetation being a very small (0.5ha) area of rushland. The breakdown of dominant vegetation classes and main species in the lake body are shown in Fig. 7, with Fig. 8 showing aquatic margin vegetation and lake macrophyte percentage cover. A summary of the key attributes of the lake macrophyte assemblage is provided in Table 5. Raw data are provided in Appendix 3, with a with a description of the macrophyte species recorded in Appendix 4.

As described in 2013, the small area of aquatic margin was dominated by the saltmarsh rush wiwi (*Juncus edgariae*) and *Carex secta*. A total of 11 macrophyte species were recorded in 2019, which was slightly greater than in previous surveys, but the dominant taxa appear largely similar (Table 5). Macrophytes were present across 18ha (37%) of the lake body, with an estimated average overall cover of 23% being slightly greater than in earlier surveys (Table 5). The densest cover was around the lake shore margins, with most of central 63% of the lake being bare (Fig. 7, Fig. 8). The maximum depth at which macrophytes was recorded was 2.9m, but beyond ca 2.4m cover was sparse (<5%). By comparison, in 2013 macrophytes were reported from depths of <2.2m. The relatively sparse overall macrophyte cover is likely attributable to the low water clarity noted above, restricting the maximum depth at which plants can grow.

Most conspicuous across most vegetated depths was the emergent blunt pondweed *Potamogeton ochreatus*, which was present across 25% of the lake, with an overall coverage of the lake bed being 12% (Appendix 3c). Subdominant were the charophyte *Chara corallina*, which was most evident at depths exceeding 1m, probably reflecting the tolerance of this species to low light (although *C. fibrosa* was recorded at shallower depths). The turfing *Glossostigma elatonoides* along with milfoil (*Myriophyllum* spp.), Horse's mane weed (*Ruppia polycarpa*), and occasional *Lilaeopsis ruthiana* were present in the shallow lake shore margin. The only non-indigenous species recorded were Canadian pondweed *Elodea canadensis* and the water buttercup *Ranunculus trichophyllus*. Eleven of the locations surveys had at least one of these species present. Where present, the average cover of *Elodea* (32%) and *Ranunculus* (8%) was relatively high (Appendix 3c), however their collective areal coverage was very low, with 98% of lake vegetation consisting of native macrophytes (Table 5).

Examples of lake vegetation of various heights, clockwise from left: *Potamogeton, Elodea,* and *Glossostigma*

Aquatic Margin Dominant Class	Ha	%
Rushland	0.5	100
Total	**0.5**	**100**

Lake Body Dominant Class	Ha	%
Charophyte	3.0	6
Macrophyte	11.8	25
Seagrass	1.0	2
Turf plants	2.0	4
Unvegetated	30.4	63
Total	**48**	**100**

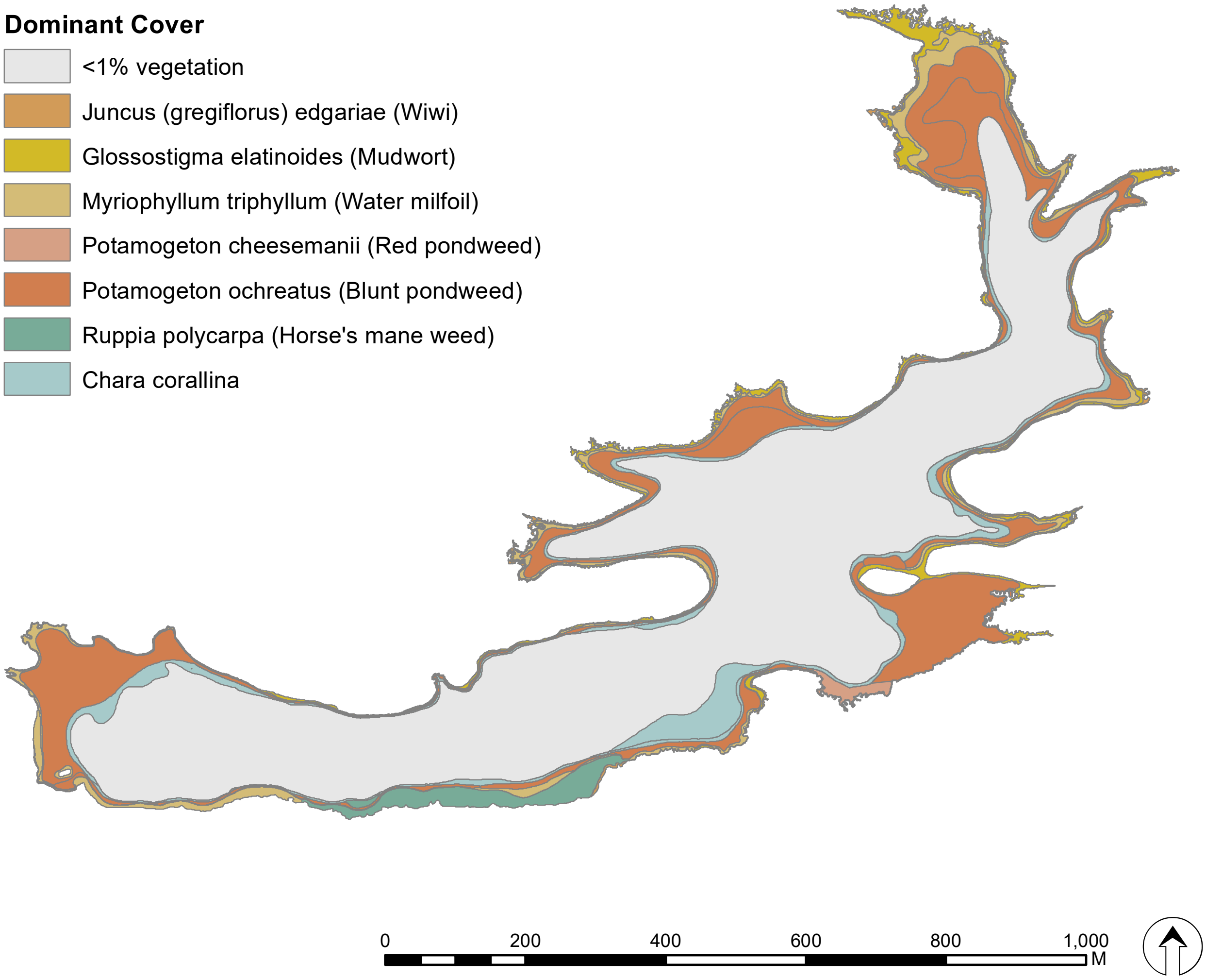

Figure 7. Map of dominant vegetation classes and summary statistics for the main species in The Reservoir, including the aquatic margin. Percentages of vegetation and bare space in the lake body are of the total area of 48ha.

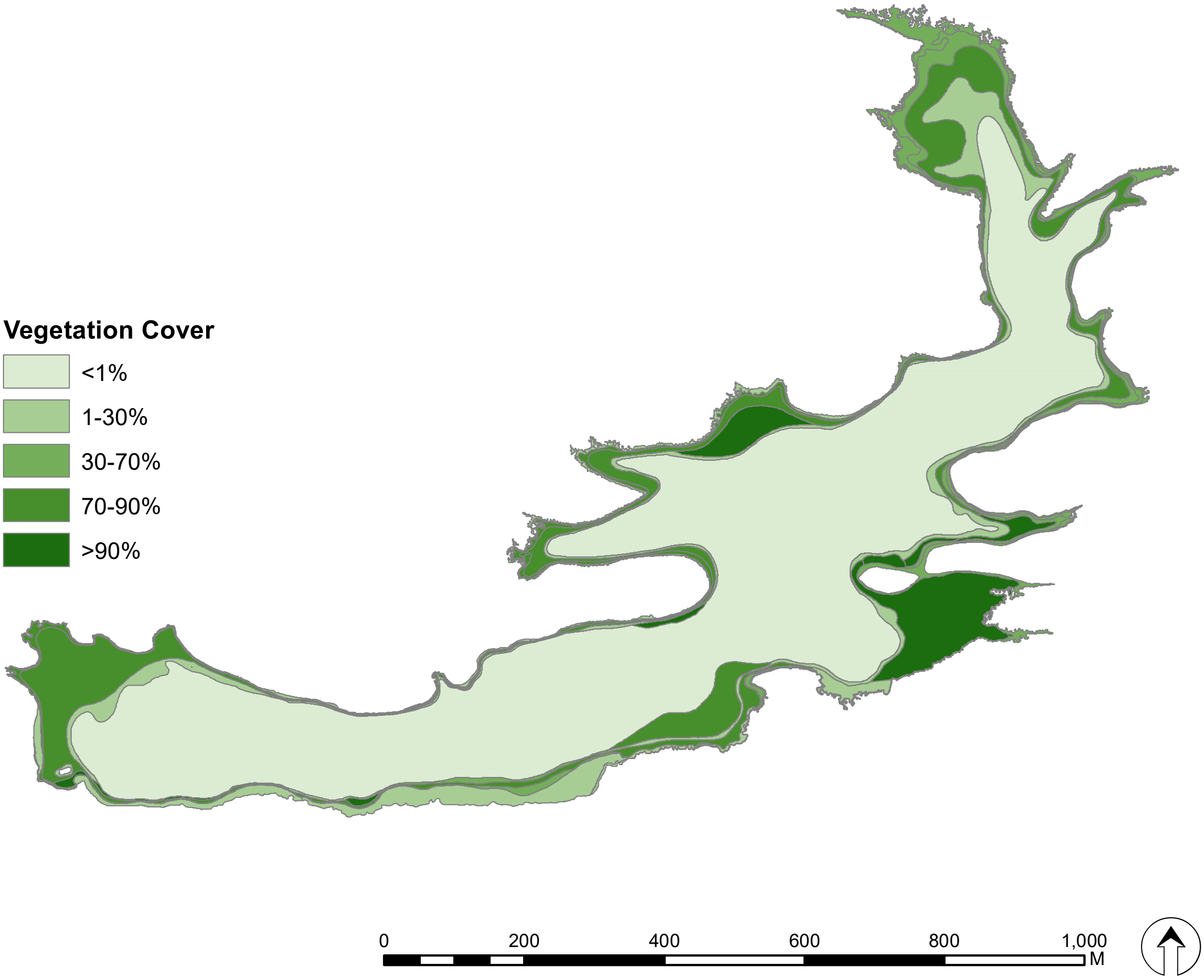

Figure 8. Vegetation percentage cover classes in The Reservoir, including the aquatic margin.

Table 5. Summary of attributes of The Reservoir macrophytes in 2019 compared with other years. Data sources as indicated in Section 3.5. Total % cover is based on the 48ha lake area excluding emergent rushland.

Note that survey methods used in 2004, 2012 and 2014 (transect sampling) differed from the lake-scale mapping approaches in 2013 and 2019. As such, differences should be interpreted with caution.

Macrophyte attribute	Mar 2004	Mar 2012	Feb 2013	Nov 2014	Mar 2019
% of lake with >1% macrophyte cover	-	-	35	-	37
Total weighted macrophyte % cover	10	16	21	na	23
Percent cover native	na	na	94	na	98
Maximum colonisation depth	na	na	2.2	2.5	2.9
Total no. macrophyte species	7	4	7	9	11
Macrophyte species (* = non-indigenous):					
Chara corallina		x		x	x
Chara fibrosa				x	x
Elatine gratioloides	x				
*Elodea canadensis**	x	x			x
Glossostigma elatonoides	x		x	x	x
Lilaeopsis ruthiana				x	x
Limosella lineata	x				
Myriophyllum proponquum	x				x
Myriophyllum triphyllum	x		x	x	x
Nitella hookeri			x		
Potamogeton cheesmanii			x	x	x
Potamogeton ochreatus	x	x	x	x	x
*Ranunculus trichophyllus**	x	x	x		x
Ruppia polycarpa			x	x	x
Triglobin striata				x	
Other algal species:					
Filamentous algal epiphyte					x

Southwestern end of The Reservoir near the outlet

5. SYNTHESIS AND RECOMMENDATIONS

5.1 SYNTHESIS OF KEY FINDINGS

The lake water body and aquatic margin of The Reservoir comprised an area of 48.5ha, of which the aquatic margin was very small (0.5ha) and dominated by the saltmarsh rush wiwi (*Juncus edgariae*) and *Carex secta*. There has been no substantive changes in marginal vegetation or lake macrophytes since the last broad scale survey in 2013. Eleven different macrophyte species were present in 2019, which was slightly greater than in 2013 and other surveys. Macrophytes occurred to varying extents across ca 37% of the lake body, with the deeper central lake area being bare. No macrophytes were found deeper than 2.9m, relative to a total lake depth of ca 6m.

When the total percent cover of macrophytes in different areas was accounted for, it was estimated that 23% of the total lake bed was vegetated, which is similar to estimate derived from earlier surveys where comparable methods were used, and falls well short of the >50% coverage recommended to ensure a clear water state. Macrophytes were dominated by blunt pondweed *Potamogeton ochreatus*, with a range of subdominant species typical of freshwater systems, with little evidence of a saline influence despite The Reservoir's close proximity to the sea (Burton et al. 2015). This is likely due to its elevation approximately 13m above sea level. Although charophytes were present, there was an absence of deeper charophyte meadows that develop under higher water clarity conditions (Burton et al. 2015). The only non-indigenous species recorded were Canadian pondweed *Elodea canadensis* and the water buttercup *Ranunculus trichophyllus*. However, these two species had a very low cover and have been described previously in The Reservoir.

The high levels of nutrients and chl-a evident from a cursory synthesis of water quality data likely reflect the combination of inputs from the primarily agricultural catchment, and the poor flushing characteristics of The Reservoir (i.e. a theoretical residence time of 55 days). These results indicate that The Reservoir is eutrophic and at times hypertropic (i.e. extremely eutrophic) with respect to TN, TP and chl-a.

Despite these high nutrient concentrations, the limited areal coverage of macrophytes in The Reservoir most likely reflects a combination of relatively deep water across much of the lake basin combined with moderate to poor water clarity. This restricts aquatic vegetation primarily to the margins (Robertson & Stevens 2013a; Burton et al. 2015). For such reasons, Schallenberg and Kelly (2012) rated The Reservoir as the most vulnerable of the lakes in their study, describing it as being in moderate to poor ecological health relative to other shallow lakes nationwide. Schallenberg and Sorrell (2009) noted that macrophyte collapses in shallow lakes, and regime shifts to a turbid plankton-dominated state, are correlated with the percentage of pasture in the catchment and also the presence of invasive macrophytes and fish.

Hamill et al. (2014) indicate total nutrient loads are perhaps more ecologically relevant to brackish lake systems than in-lake nutrient concentrations, but further work is needed to understand variation in vulnerabilities among systems as well as to standardise and verify nutrient loading measurement methodologies (e.g. Snelder et al. 2014). Consequently, no national guidance has been set for nitrogen and phosphorus loading rates at this time. However, losses of seagrass habitat are reported to occur in well-flushed estuaries at TN loads >20-50mg $N/m^2/d$, (Robertson 2018). Maintaining TN inputs at or below the lower range provides interim guidance for avoiding adverse eutrophication conditions in largely closed systems like The Reservoir where low flushing means nutrient inputs will accumulate in both water and sediments.

Estimates of catchment nutrient loads (TN and TP) have been made using inputs modelled on defined land use types (Appendix 5). These estimates do not include local scale adjustments for fertiliser applications or stocking rates which are expected to increase predicted loads. For TN, the estimated areal load of 17.6mg $N/m^2/d$ indicates that The Reservoir is likely at, or above, the threshold where the potential for adverse ecological impacts may be expected to occur. This is consistent with water quality monitoring results.

Overall, the high nutrient and chl-a concentrations measured in 2019 indicate the presence of excessive nutrients, and phytoplankton blooms are occurring in the deeper waters of the lake. However, despite the apparent pressures on The Reservoir, the 2019 survey results do not suggest that it has become significantly degraded in state from the assessments made previously although it clearly still appears vulnerable to the range of risk factors highlighted.

5.2 RECOMMENDATIONS

Various studies have been undertaken in The Reservoir over the past decade focusing on many different aspects of lake ecology, with recommendations made for ongoing assessment. While not coordinated in any way, the different studies have made generally similar monitoring recommendations. Schallenberg and Kelly (2012) highlight that key aspects to monitor and manage for Southland Lakes in general are the maintenance and enhancement of lake macrophyte communities, controlling the downstream impacts of agricultural land uses in their catchments, and preventing the spread of invasive pest species. Similarly, Burton et al. (2015) recommended continued work on the lakes to understand and mitigate any threats to their long term ecological condition, given that the shallow nature of the lake systems makes them particularly vulnerable to change over a short time frame.

Specific to The Reservoir, Robertson and Stevens (2013a) recommended efforts to:

- Reduce total phosphorus loads to the lake so that it returns to a mesotrophic condition, supported by desktop calculations to determine appropriate nutrient load guidelines.
- Take actions to improve water clarity if feasible (e.g. by reducing P input loads) to increase macrophyte cover to a target of >50%.
- Maintain or improve on the currently low level of non-indigenous macrophytes.
- Undertake similar broad scale monitoring at intervals of ca 5 years.

In addition to the above, it is recommended that current water quality monitoring in the lake continue. We also suggest that it would be timely to undertake a more in-depth analysis of the water quality data, to consider trends over time and potential explanatory variables.

Beyond these specific recommendations, if ES intend to take actions to improve the state of The Reservoir, or at least minimise the risk of further degradation, we emphasise the importance of defining appropriate lake management objectives. This will help to define and optimise a long-term monitoring programme accordingly, in order to track changes in the state of the lake, and the effectiveness of any management initiatives. The design of any such monitoring programme should target the key stressors on the lake, and identify the data needs, methods, resolution and frequency required to detect changes in catchment pressures and responses in lake ecology within a time frame appropriate for effective management.

It is recommended that a desktop review of the current long-term sampling design be conducted prior to undertaking any further broad scale habitat monitoring, incorporating key lake attributes and supporting monitoring indicators that Environment Southland are currently developing.

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APPENDICES

APPENDIX 1. VEGETATION AND SEDIMENT CLASSES

VEGETATION

Tussockland: Vegetation in which the cover of tussock in the canopy is 20-100% and in which the tussock cover exceeds that of any other growth form or bare ground. Tussock includes all grasses, sedges, rushes, and other herbaceous plants with linear leaves (or linear non-woody stems) that are densely clumped and >100 cm height. Examples of the growth form occur in all species of *Cortaderia, Gahnia,* and *Phormium*, and in some species of *Chionochloa, Poa, Festuca, Rytidosperma, Cyperus, Carex, Uncinia, Juncus, Astelia, Aciphylla,* and *Celmisia.*

Rushland: Vegetation in which the cover of rushes (excluding tussock-rushes) in the canopy is 20-100% and where rush cover exceeds that of any other growth form or bare ground. A tall grasslike, often hollow-stemmed plant, included in rushland are some species of *Juncus* and all species of *Apodasmia (Leptocarpus)*.

SEDIMENT

Rock field: Land in which the area of residual rock exceeds the area covered by any one class of plant growth-form. They are named from the leading plant species when plant cover is ≥1%.

Boulder field: Land in which the area of unconsolidated boulders (>200mm diam.) exceeds the area covered by any one class of plant growth-form. Boulder fields are named from the leading plant species when plant cover is ≥1%.

Cobble field: Land in which the area of unconsolidated cobbles (20-200 mm diam.) exceeds the area covered by any one class of plant growth-form. Cobble fields are named from the leading plant species when plant cover is ≥1%.

Gravel field: Land in which the area of unconsolidated gravel (2-20 mm diameter) exceeds the area covered by any one class of plant growth-form. Gravel fields are named from the leading plant species when plant cover is ≥1%.

Sand: Granular beach sand with no conspicuous fines evident when sediment is disturbed i.e. a mud content <1%. Classified as firm sand if an adult sinks <2 cm, soft sand if an adult sinks >2 cm, or mobile when characterised by a rippled surface layer from tidal currents or wind-generated waves.

Muddy sand (Low mud content): A sand/mud mixture dominated by sand with a low mud fraction (e.g. 1-10%), the mud fraction conspicuous only when sediment is mixed in water. Granular when rubbed between the fingers. Classified as firm if you sink 0-2 cm when walking, soft if you sink 2-5cm, or mobile when characterised by a rippled surface layer.

Muddy sand (Moderate mud content): A subjective division may be applied where the sand/mud mixture remains dominated by sand, but has an elevated mud fraction (i.e. 10-25%). Granular when rubbed between the fingers, but with a smoother consistency than muddy sand with a low mud fraction, the mud fraction visually conspicuous when walking on it. Classified as firm if you sink 0-2 cm when walking, soft if you sink 2-5cm, or mobile when characterised by a rippled surface layer.

Sandy mud (High mud content): A mixture of mud and sand where mud is a major component (i.e. >25%-50% mud). Sediment rubbed between the fingers is primarily smooth/silken but retains a granular component. Sediments generally soft and only firm if dried out or another component e.g. gravel prevents sinking. Classified as firm if you sink 0-2 cm when walking, soft if you sink 2-5cm, or very soft if you sink >5cm.

Sandy mud (Very high mud content): A mixture of mud and sand where mud is the dominant component (e.g. >50% mud). Sediment rubbed between the fingers may retain a slight granular component but is primarily smooth/silken. Sediments generally very soft and only firm if dried out or another component e.g. gravel prevents sinking. Classified as firm if you sink 0-2 cm when walking, soft if you sink 2-5cm, or very soft if you sink >5cm.

Mud (>90% mud content): A strongly mud dominated substrate with sand a minor component. Smooth/silken when rubbed between the fingers. Sediments generally very soft and only firm if dried out or another component e.g. gravel prevents sinking. Classified as firm if you sink 0-2 cm when walking, or soft if you sink >2 cm.

APPENDIX 2. RJ HILL ANALYTICAL METHODS

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively clean matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.
Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Sediment

Test	Method Description	Default Detection Limit	Sample No
Individual Tests			
Environmental Solids Sample Drying*	Air dried at 35°C Used for sample preparation. May contain a residual moisture content of 2-5%.	-	1-21
Environmental Solids Sample Preparation	Air dried at 35°C and sieved, <2mm fraction. Used for sample preparation. May contain a residual moisture content of 2-5%.	-	1-21
Dry Matter for Grainsize samples (sieved as received)*	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd	1-21
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	1-21
Total Recoverable Phosphorus	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	40 mg/kg dry wt	1-21
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg	Dried sample, <2mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, trace level.	0.010 - 0.4 mg/kg dry wt	1-21
Total Organic Carbon and Total Nitrogen*	Catalytic Combustion (900°C, O_2), separation, Thermal Conductivity Detector [Elementar Analyser]	-	1-21
3 Grain Sizes Profile as received			
Fraction >/= 2 mm*	Wet sieving with dispersant, as received, 2.00 mm sieve, gravimetry.	0.1 g/100g dry wt	1-21
Fraction < 2 mm, >/= 63 µm*	Wet sieving using dispersant, as received, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-21
Fraction < 63 µm*	Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-21

APPENDIX 3.
A) SUMMARY DATA ON DOMINANT VEGETATION

Class & Dominant Cover	Subdominant 1	Subdominant 2	Subdominant 3	Ha	%
AQUATIC MARGIN				**0.5**	**100**
Rushland				**0.5**	**100**
Juncus (gregiflorus) edgariae				0.4	
	Carex secta			0.02	
	Glossostigma elatinoides			0.1	
	Ranunculus trichophyllus			0.01	

Class & Dominant Cover	Subdominant 1	Subdominant 2	Subdominant 3	Ha	%
LAKE BODY				**48.2**	**100**
Charophyte				**3.0**	**6.2**
Chara corallina				2.1	
	Elodea canadensis; Ranunculus trichophyllus			0.0	
	Potamogeton ochreatus			0.8	
	Potamogeton ochreatus; Elodea canadensis			0.1	
Macrophyte				**11.8**	**24.5**
Myriophyllum triphyllum	*Elodea canadensis*			0.1	
	Elodea canadensis; Potamogeton ochreatus			1.2	
	Potamogeton ochreatus			0.7	
	Ranunculus trichophyllus			0.0	
	Ranunculus trichophyllus; Ruppia polycarpa			0.1	
	Ruppia polycarpa; Ranunculus trichophyllus; Potamogeton ochreatus			0.3	
Potamogeton cheesemanii				0.2	
Potamogeton ochreatus				3.6	
	Chara corallina			2.9	
	Myriophyllum triphyllum			2.4	
	Myriophyllum triphyllum; Ruppia polycarpa			0.0	
	Potamogeton cheesemanii			0.1	
	Potamogeton cheesemanii; Chara corallina; Chara fibrosa			0.2	
Seagrass				**1.0**	**2.1**
Ruppia polycarpa	*Myriophyllum triphyllum; Potamogeton ochreatus; Ranunculus trichophyllus*			0.0	
	Myriophyllum triphyllum; Ranunculus trichophyllus			1.0	
Turf Plant				**2.0**	**4.2**
Glossostigma elatinoides	*Myriophyllum triphyllum*			0.5	
	Myriophyllum triphyllum; Juncus (gregiflorus) edgariae; Chara fibrosa			0.8	
	Myriophyllum triphyllum; Juncus (gregiflorus) edgariae			0.1	
	M. triphyllum; R. amphitrichus; M. propinquum; Carex secta; J. edgariae			0.6	
<1% vegetation				**30.4**	**63.1**

B) POINT ESTIMATES FROM STATIONS SHOWN IN FIG. 2 OF MAIN REPORT

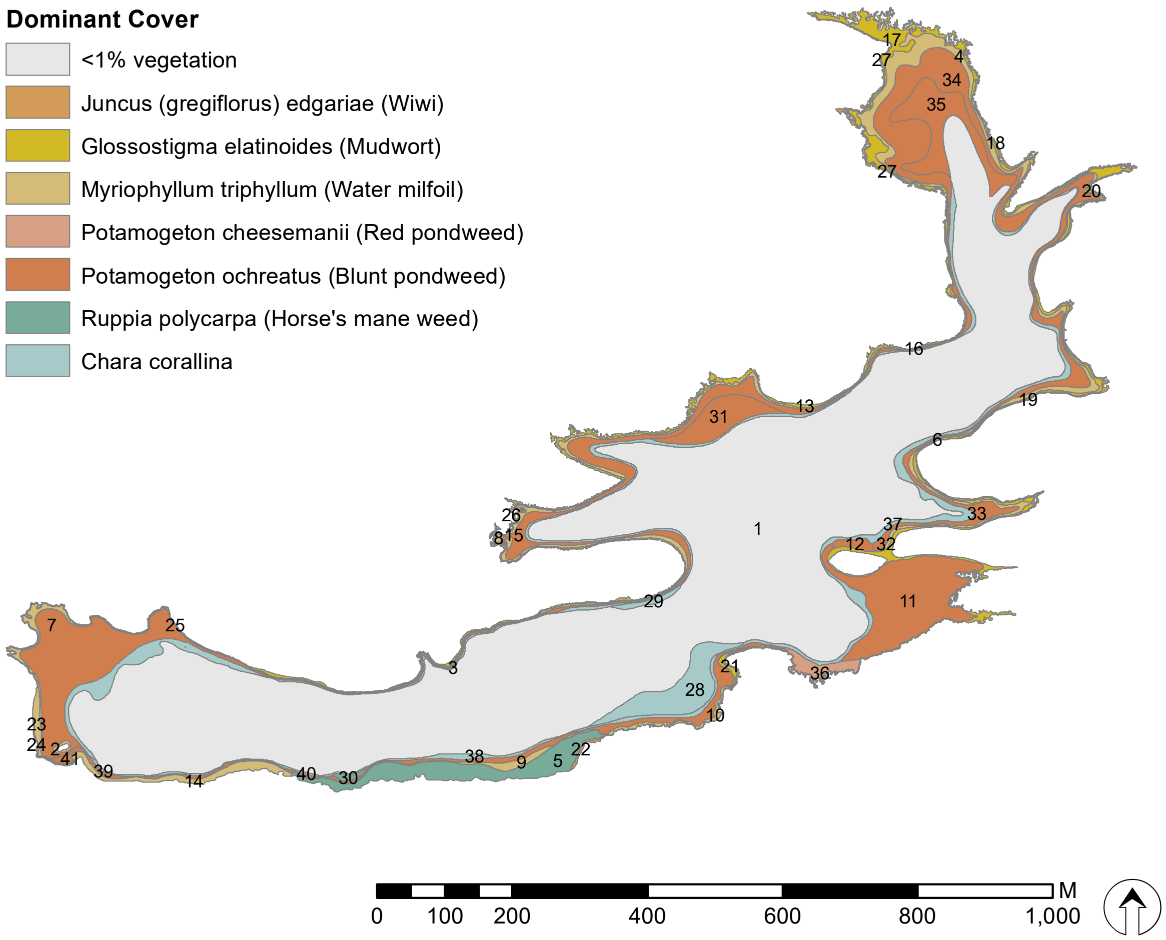
Sample Station	NZTM North	NZTM East	Depth (m)	Sediment type	aRPD (mm)	Bare space	chco	chfi	elca	glel	liru	mypr	mytr	pooc	poch	ratr	rupo
A1	4826115	1298680	0.5	fSMvh	20	10				80		5		5			
A2	4826115	1298686	0.9	fSMvh	0	0								100			
A3	4826103	1298702	1.6	vsSMvh	0	0								100			
A4	4826089	1298711	2.1	vsSMvh	5	95								5			
A5	4826085	1298715	2.3	-	-	100											
A6	4826083	1298800	2.4	-	-	100											
A7	4826078	1298828	1.6	vsSMvh	2	0								100			
A8	4826078	1298835	0.8	sSMvh	30	0		4					1	95			
B1	4826783	1298977	0.6	sSMvh	100	10		10	5			2	3	70			
B2	4825975	1298794	2.3	sSMvh	2	94	1							5			
B3	4825830	1298978	2.9	vsSMvh	5	99	1										
B4	4826000	1298864	1.7	vsSMvh	2	94	1							5			
B5	4826008	1298864	1.0	sSMvh	5	0	10							90			
C1	4825766	1298819	1.8	sSMvh	5	20	50							30			
C2	4825758	1298836	3.5	-	-	100											
C3	4825728	1298858	3.6	vsSMvh	1	100											
C4	4825656	1298864	1.5	sSMvh	45	20	79				1						
C5	4825655	1298871	0.6	sSMvh	0	50		30		15				5			
D1	4825661	1298605	0.9	sSMvh	5	20	20	35		15	5			5			
D2	4825655	1298610	3.2	vsSMvh	5	100											
D3	4825594	1298679	4.0	vsSMvh	1	100											
D4	4825593	1298677	1.4	fSMvh	0	100											
D5	4825565	1298733	0.6	fSMvh	0	50				30	20						
D6	4825498	1298798	3.8	-	-	100											
D7	4825510	1298800	1.8	fSMvh	5	0	9	1						70	20		
E0	4825608	1298431	1.9	vsSMvh	0	0								100			
E1	4825605	1298426	2.2	vsSMvh	5	100											
E2	4825509	1298479	3.6	-	-	100											
E3	4825315	1298564	3.3	vsSMvh	2	100								0			
E4	4825270	1298597	2.2	vsSMvh	5	0								100			
F1	4825362	1298351	1.6	sSMvh	0	0	60		10					30			
F2	4825296	1298352	4.6	-	-	100											
F3	4825275	1298348	4.6	vsSMvh	1	100											
F4	4825234	1298350	2.3	fMSl	10	20	70							10			
F5	4825150	1298211	0.6	fMSl	100	85							5				10
G1	4825229	1297936	2.1	vsSMvh	5	0	50							50			
G2	4825234	1297929	4.0	-	-	100											
G3	4825190	1297916	4.5	vsSMvh	1	100											
G4	4825191	1297911	3.3	-	-	100											
G5	4825108	1297895	0.4	fMSl	5	30							10	5		5	50
H1	4825284	1297621	2.6	vsSMvh	5	95								5			
H2	4825272	1297626	2.7	-	-	100											
H3	4825210	1297611	3.2	vsSMvh	5	100											
H4	4825122	1297596	3.7	-	-	100											
H5	4825106	1297596	1.2	fMSl	15	0	60		30							10	
H6	4825106	1297600	0.3	fMSl	150	50							20	5		5	20

NOTES:

f=firm, s=soft, vs=verysoft, MS=muddy sand, SM=sandy mud, l=1-10%mud, m=>10-25%mud, h=>25-50%mud, vh=>50%mud

chco=Chara corallina, chfi=Chara fibrosa, elca=Elodea canadensis, glel=Glossostigma elatinoides, liru=Lilaeopsis ruthiana, mypr=Myriophyllum propinquum mytr=Myriophyllum triphyllum, pooc=Potamogeton ochreatus, poch=Potamogeton cheesemanii, ratr=Ranunculus trichophyllus, rupo=Ruppia polycarpa

C) GIS SUMMARY MAP AND DATA



Id	Depth (m)	FieldCode	Class	DomHab	SubDom1	SubDom2	Other SubDoms	PctCvr	%Class	ha	%
1	>2.5	bare	<1% vegetated					<1	Trace <1%	30.4	62.4
2	0.0-0.5	mytr ratr	Macrophyte	Myriophyllum triphyllum	Ranunculus trichophyllus			1-30	Sparse 1-30%	0.02	0.04
3	2.0-2.5	chco	Charophyte	Chara corallina				1-30	Sparse 1-30%	1.0	2.1
4	0.5-1.0	mytr elca pooc	Macrophyte	Myriophyllum triphyllum	Elodea canadensis	Potamogeton ochreatus		30-70	Moderate 30-70%	1.1	2.2
5	0.0-0.5	rupo mytr ratr	Seagrass	Ruppia polycarpa	Myriophyllum triphyllum	Ranunculus trichophyllus		1-30	Sparse 1-30%	1.0	2.0
6	0.0-0.5	glel mytr jugr chfi	Turf Plant	Glossostigma elatinoides	Myriophyllum triphyllum	Juncus (gregiflorus) edgar	Chara fibrosa	30-70	Moderate 30-70%	0.8	1.7
7	1.5-2.0	pooc	Macrophyte	Potamogeton ochreatus				70-90	Dense 70-90%	3.6	7.4
8	0.5-1.0	mytr pooc	Macrophyte	Myriophyllum triphyllum	Potamogeton ochreatus			70-90	Dense 70-90%	0.7	1.4
9	0.5-1.0	mytr elca pooc	Macrophyte	Myriophyllum triphyllum	Elodea canadensis	Potamogeton ochreatus		30-70	Moderate 30-70%	0.1	0.3
10	0.5-1.0	mytr elca	Macrophyte	Myriophyllum triphyllum	Elodea canadensis			1-30	Sparse 1-30%	0.1	0.2
11	1.5-2.5	pooc mytr	Macrophyte	Potamogeton ochreatus	Myriophyllum triphyllum			>90	Complete >90%	1.8	3.7
12	1.5-2.5	pooc poch	Macrophyte	Potamogeton ochreatus	Potamogeton cheeseman			>90	Complete >90%	0.1	0.2
13	0.0-0.5	glel mytr	Turf Plant	Glossostigma elatinoides	Myriophyllum triphyllum			1-30	Sparse 1-30%	0.04	0.1
14	0.0-0.5	mytr rupo ratr pooc	Macrophyte	Myriophyllum triphyllum	Ruppia polycarpa	Ranunculus trichophyllus	Potamogeton ochreatus	1-30	Sparse 1-30%	0.3	0.6
15	0.0-0.5	glel mytr	Turf Plant	Glossostigma elatinoides	Myriophyllum triphyllum			1-30	Sparse 1-30%	0.5	1.0
16	0.0-0.5	glel mytr jugr	Turf Plant	Glossostigma elatinoides	Myriophyllum triphyllum	Juncus (gregiflorus) edgar		30-70	Moderate 30-70%	0.1	0.1
17	0.0-0.5	glel mytr raam mypr casx jugr	Turf Plant	Glossostigma elatinoides	Myriophyllum triphyllum	Ranunculus amphitrichus	M. propinquum; Carex secta; J. edgariae	30-70	Moderate 30-70%	0.6	1.3
18	0.0-0.5	jugr	Emergent	Juncus (gregiflorus) edgariae				30-70	Moderate 30-70%	0.1	0.1
19	0.0-0.5	jugr	Emergent	Juncus (gregiflorus) edgariae				30-70	Moderate 30-70%	0.1	0.3
20	0.0-0.5	jugr	Emergent	Juncus (gregiflorus) edgariae				30-70	Moderate 30-70%	0.1	0.1
21	0.0-0.5	jugr casx	Emergent	Juncus (gregiflorus) edgariae	Carex secta			30-70	Moderate 30-70%	0.02	0.04
22	0.0-0.5	jugr	Emergent	Juncus (gregiflorus) edgariae				1-30	Sparse 1-30%	0.02	0.1
23	0.0-0.5	mytr ratr rupo	Macrophyte	Myriophyllum triphyllum	Ranunculus trichophyllus	Ruppia polycarpa		1-30	Sparse 1-30%	0.1	0.2
24	0.0-0.5	jugr ratr	Emergent	Juncus (gregiflorus) edgariae	Ranunculus trichophyllus			1-30	Sparse 1-30%	0.01	0.01
25	0.0-0.5	jugr casx	Emergent	Juncus (gregiflorus) edgariae	Carex secta			1-30	Sparse 1-30%	0.002	0.004
26	0.0-0.5	jugr glel	Emergent	Juncus (gregiflorus) edgariae	Glossostigma elatinoides			1-30	Sparse 1-30%	0.1	0.2
27	0.0-0.5	jugr	Emergent	Juncus (gregiflorus) edgariae				30-70	Moderate 30-70%	0.1	0.3
28	>2.5	chco pooc	Charophyte	Chara corallina	Potamogeton ochreatus			70-90	Dense 70-90%	0.8	1.6
29	>2.5	chco pooc elca	Charophyte	Chara corallina	Potamogeton ochreatus	Elodea canadensis		>90	Complete >90%	0.1	0.1
30	2.0-2.5	rupo mytr pooc ratr	Seagrass	Ruppia polycarpa	Myriophyllum triphyllum	Potamogeton ochreatus	Ranunculus trichophyllus	>90	Complete >90%	0.0	0.1
31	2.0-2.5	pooc mytr	Macrophyte	Potamogeton ochreatus	Myriophyllum triphyllum			>90	Complete >90%	0.5	1.1
32	1.5-2.0	pooc poch chco chfi	Macrophyte	Potamogeton ochreatus	Potamogeton cheeseman	Chara corallina	Chara fibrosa	>90	Complete >90%	0.1	0.1
33	1.5-2.0	pooc poch chco chfi	Macrophyte	Potamogeton ochreatus	Potamogeton cheeseman	Chara corallina	Chara fibrosa	>90	Complete >90%	0.2	0.4
34	1.5-2.0	pooc chco	Macrophyte	Potamogeton ochreatus	Chara corallina			70-90	Dense 70-90%	2.0	4.2
35	1.5-2.0	pooc chco	Macrophyte	Potamogeton ochreatus	Chara corallina			1-30	Sparse 1-30%	0.9	1.8
36	1.5-2.0	poch	Macrophyte	Potamogeton cheesemanii				1-30	Sparse 1-30%	0.2	0.4
37	2.0-2.5	chco	Charophyte	Chara corallina				1-30	Sparse 1-30%	0.9	1.8
38	2.0-2.5	chco	Charophyte	Chara corallina				30-70	Moderate 30-70%	0.1	0.2
39	2.0-2.5	chco elca ratr	Charophyte	Chara corallina	Elodea canadensis	Ranunculus trichophyllus		>90	Complete >90%	0.05	0.1
40	2.0-2.5	chco	Charophyte	Chara corallina				1-30	Sparse 1-30%	0.04	0.1
41	1.5-2.0	pooc mytr rupo	Macrophyte	Potamogeton ochreatus	Myriophyllum triphyllum	Ruppia polycarpa		>90	Complete >90%	0.04	0.1
										48.7	100

APPENDIX 4. MACROPHYTE DESCRIPTIONS

Lake Vegetation

Species	Type	Status
Ruppia polycarpa	Emergent	Native

(Horse's mane weed)

R. polycarpa is a surface-flowering, submerged, aquatic annual or perennial herb. Stems grow to 50cm long, depending on water depth. Vegetative buds (turions) can be formed in some ephemeral habitats. It grows in fresh to hypersaline coastal lakes, lagoons and estuaries and is relatively common in the 0-1.5m depth range (depending on water clarity). It grows in sandy sediments, and has distinctive flowers terminal on white stalks.

Species	Type	Status
Ruppia megacarpa	Emergent	Native

(Horse's mane weed)

R. megacarpa is a surface-flowering, submerged, aquatic perennial herb. Common in relatively shallow (~2m) permanent water (salinity range 5-46 PSS), although seeds require salinities in the lower end of range to germinate. Grows slowly and matures later, producing fewer, larger seeds than *R. polycarpa*. Seeds germinate and form seedlings in spring, with flowering and fruiting occur in summer and autumn.

Species	Type	Status
Potamogeton ochreatus	Emergent	Native

(Blunt pondweed)

P. ochreatus is a common pondweed species, tolerant of slightly brackish as well as fresh water. It survives low light and temperatures, and prefers high nutrient water. It forms dense mats of vegetation up to the water surface. It germinates in autumn, grows vigorously in spring, and dies off in the late summer. Decaying plant matter can make the water enriched and encourage nuisance algal mats near the sediment surface.

Species	Type	Status
Potamogeton cheesemanii	Emergent	Native

(Red pondweed)

P. cheesemanii is a widespread pondweed species that is tolerant of slightly brackish as well as fresh water. It is a submerged or floating, rhizomatous sparsely branched perennial herb. Rhizomes rooting at nodes and producing mostly simple leafy branches; these ultimately emerge at the water surface. A common plant of ponds, lake margins and slowly flowing streams. Flowering occurs Nov-March and fruiting Dec-March.

Myriophyllum triphyllum	Emergent	Native

M. triphyllum is a widespread submerged perennial milfoil species. Plants grow to 3m tall, and have emergent and submerged leaves. Emergent leaves are reddish, ovate, entire or lobed. Submerged leaves are 10-15mm long, finely pinnate in whorls. Plants have small reddish flowers and globular fruit.

Lilaeopsis ruthiana	Turf	Native

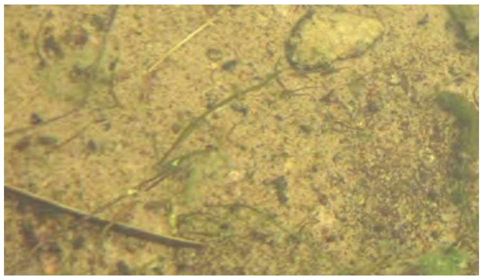
L. ruthiana is a submerged vascular turf macrophyte, rooted in substrate. It is a creeping herb with cylindrical septate leaves (2-5cm long). It is vegetatively similar to *L. novae-zelandiae,* but leaves are often finer with paler septa. Like *Ruppia,* it is rhizome creeping. Plants are widespread in damp margins of waterways.

Glossostigma elatinoides	Turf	Native

Submerged vascular turf macrophyte, rooted in substrate. Spatulate leaves, loose mats with leaves in pairs not tufts like *Limosella*. Widespread in North and South Islands.

Limosella lineata	Turf	Native

Submerged vascular turf macrophyte, rooted in substrate. Loose mats with leaves in tufts. Widespread in North and South Islands.



Ranunculus amphitrichus	Turf	Native

(Waoriki)

Submerged vascular turf macrophyte, rooted in substrate. Coastal to montane. Often partially submerged in shallow water, wet grassland and lake, pond or tarn marginal turf communities. Sometimes in moist clearings within forest or tussock grassland. Flowers in Oct-Jan (yellow flower).

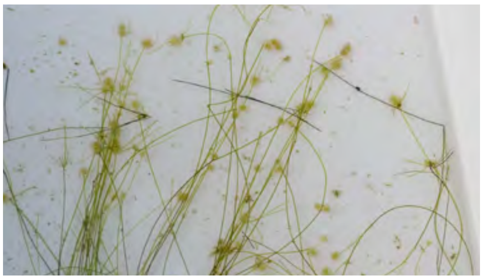
Chara corallina Charophyte Native

C. corallina is a widespread submerged bottom-dwelling green charophyte algal species, that superficially resembles flowering aquatic plants. Plants are stout and crisp with turgid segments and pinched nodes, pale to bright green. The conspicuous antheridia (male sex organs) are spherical and bright orange or yellow when mature. There are no stem divisions. It is widespread in the North and South Islands.

Chara fibrosa Charophyte Native

C. fibrosa is a relatively common bottom dwelling, grey-green charophyte algal species. Many small spines grow from a central stem (generally <0.5m) with reproductive organs found near the stem, surrounded by spines. Oospores are black. It is most common in shallows <2m.

Nitella sp. Charophyte Native



Nitella is a widespread bottom-dwelling, green charophyte algal species that superficially resembles flowering aquatic plants. It sometimes creates dense carpets on freshwater or slightly saline lagoon beds, reaching depths of 30m in some clear lakes. It is a long stringy looking plant without leaves. Stems "pop" if squeezed.

Elodea canadensis Emergent Introduced

(Canadian pondweed)

Elodea, an introduced oxygen weed, is an aquatic perennial which can grow easily from fragments and spread via vegetative growth and cause major infestations in many freshwater and slightly saline waterbodies. A problematic submerged aquatic weed.

Ranunculus trichophyllus Emergent Introduced

(Water buttercup)

R. trichophyllus (water buttercup) is common in freshwater and slightly saline waterbodies. Stems are up to 2m long, leaves are narrow and bright green. Flowers are white with a yellow centre. These mats inhibit the growth of native aquatics, and can interfere with boating and other water recreation. It germinates in autumn, grows vigorously in spring, and dies off in the summer. The decaying plant matter can make the water extremely enriched and encourage nuisance algal mats near the sediment surface.

Potamogeton crispus | Emergent | Introduced

(Curly pondweed)

P. crispus is tolerant of slightly brackish as well as freshwater. It can survive in low light and low temperatures, and prefers high nutrient water. It spreads mostly by means of vegetative buds (turions) that germinate in autumn. It forms dense mats of vegetation to the surface of the water. These mats inhibit the growth of native aquatics, and can interfere with boating and other water recreation. It germinates in autumn, grows vigorously in spring, and dies off in the summer. The decaying plant matter can make the water extremely enriched and encourage nuisance algal mats near the sediment surface.

Typha orientalis | Emergent shoreline | Native

(Raupo)

A vigorous erect clump-forming plant with spreading rhizomes. Found throughout NZ in shallow fertile waters of sheltered lakes and swamps. Leaves are pale green and large, furry brown, cylindrical seed heads, the lower female part and the narrower upper male part. The seedheads are fluffy when ripe. Raupo dies down in the winter.

Juncus edgeriae | Emergent shoreline | Native

(Wiwi or Edgars rush)

J. edgeriae is very common in coastal to alpine areas (1600 m.a.s.l.) but is mainly coastal to montane. It usually grows in open shrubland, fringing wetlands, and in seasonally damp sites. It is often found invading pasture and in urban areas. It flowers from October to December and fruits from November to April.

Carex secta | Emergent shoreline | Native (endemic)

(Purei or niggerhead)

C. secta is a tussock-forming sedge, found throughout the North, South and Stewart Islands. It is widespread in suitable wetlands from coastal to montane wetlands. It flowers from October to November and fruits from October to December.

Apodasmia similis | Emergent shoreline | Native (endemic)

(Oioi or jointed wire rush)

Formerly *Leptocarpus similis, A. similis* is a rush with dark-banded wire-like slightly zigzagging stems. It is a coastal rush but it is also found around peat bogs and hot springs. It flowers from October to December and bears fruit from December to March.

APPENDIX 5. CATCHMENT OVERVIEW