TE WAIHORA/LAKE ELLESMERE

State of the Lake and Future Management

Edited by **KENNETH F.D. HUGHEY** and **KENNETH J.W. TAYLOR**

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Edited by Hughey and Taylor

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Lincoln University Environment Canterbury

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SHELLEY McMURTRIE

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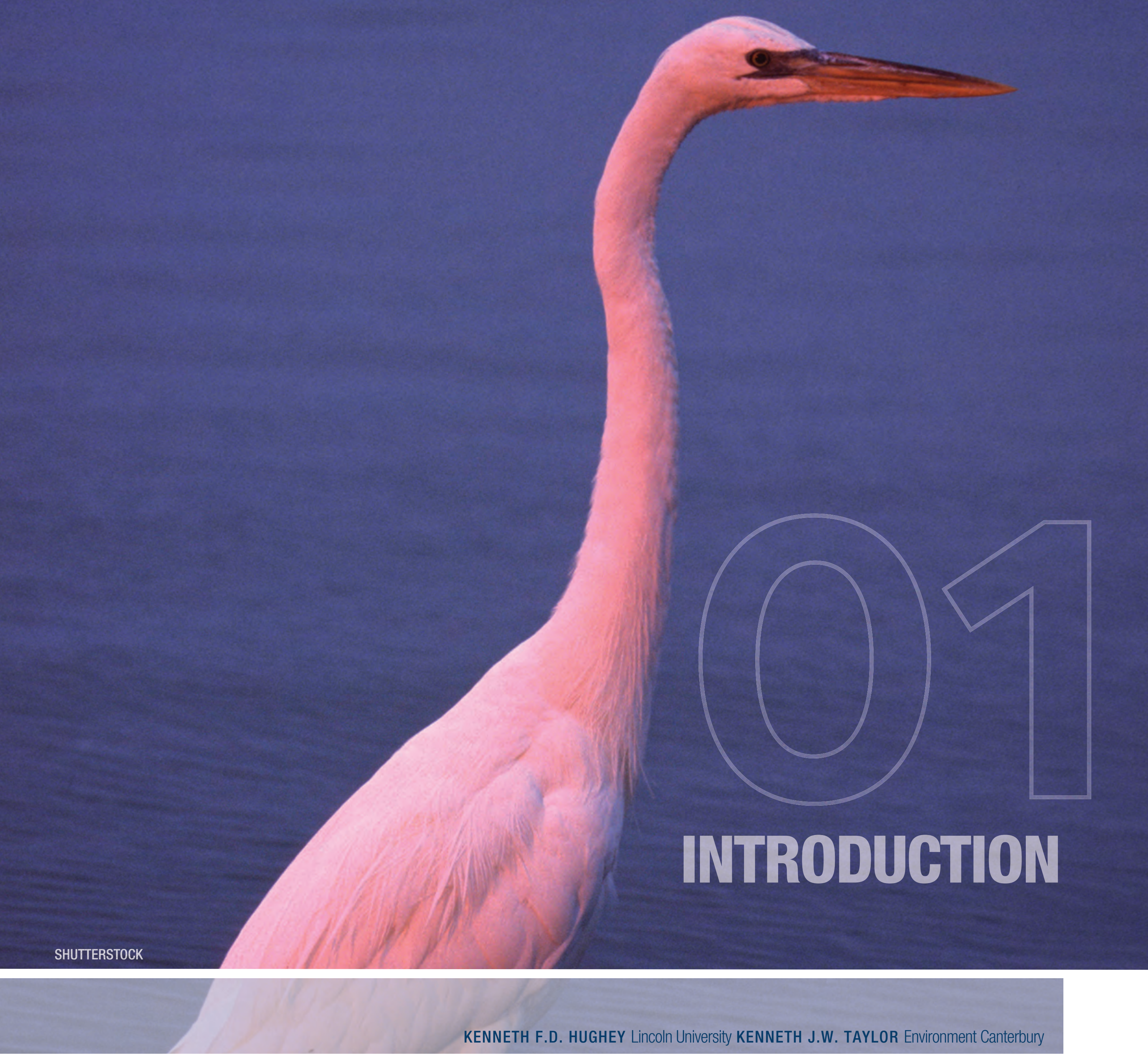
CONTENTS


SHELLEY McMURTRIE



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01

INTRODUCTION

KENNETH F.D. HUGHEY Lincoln University **KENNETH J.W. TAYLOR** Environment Canterbury

Te Waihora/Lake Ellesmere[1] is a large coastal lake, intermittently open to the sea. It is highly regarded for its conservation and related values, some of which are of international significance. Its function as a sink for nutrients from its large predominantly agriculturally based catchment, currently undergoing accelerated intensification, is also recognised, at least implicitly. It is the resulting conflict from these value sets which is mainly responsible for the ongoing debate about the future of the lake, a debate long fuelled by rhetoric and informed by a body of science which highlights the lake's complexity as a biophysical system, but has many gaps. It is a debate that now has substantial statutory implications, arising from factors which include:

- the requirements of conservation, and indigenous needs and entitlements which are growing in prominence and statutory (including property rights based) legitimacy;
- public interest in legal processes associated with further major intensification of agriculture planned for the catchment;
- a recent Environment Court decision in which serious questions about the overall biological health of the lake were raised; and
- the consequences arising from the need for Environment Canterbury to obtain resource consents for the lake operating regime.

In addition, in recent times the Waihora Ellesmere Trust (WET), a community based group advocating for improved management of the lake, has been established. It is within these diverse contexts that this State of Te Waihora/Lake Ellesmere report has been prepared—it results from the 2007 Waihora/Ellesmere Living Lake Symposium, held from 31 October-3 November 2007 at Lincoln University, Canterbury. The symposium was initiated and organised by the WET (see www.wet.org.nz).

The Living Lake Symposium had several key objectives:

- To determine the overall state of the lake, by first defining the key value sets, and indicators that could be reported against;
- To suggest future management actions that would address key issues affecting the defined values;
- To provide a forum within which lay individuals, scientists and managers could openly debate issues; and
- To provide a launching pad for integrated and focused future management of the lake and its environs.

The programme incorporated three keynote speakers: Dr Larry Hildebrand from Environment Canada, Dr Hamish Rennie from Lincoln University, and Dr Bryan Jenkins from Environment Canterbury—their addresses made a major contribution to the symposium although none are included in this report, because it is focused primarily on the science and the management options associated with the lake.

The format of this report is designed to be readily updateable. Ten of the principal presentations in the main sessions of day two of the symposium are included in this report—two Power Point presentations (both regarding water quantity and related issues) are provided as appendices to improve completeness. Over time, however, topic areas not available as full papers for this report, e.g., surface water quantity, will be written up and included in detail. Similarly, the papers herein will themselves be updated as new and significant data become available. Each subject area will be reconsidered within the same structure and context as has been provided here. One paper, 'Te Waihora/Lake Ellesmere: An integrated view of the current state and possible futures', was presented on the final formal day of the symposium and it is included as the concluding chapter of this report.

Finally, the Waihora Ellesmere Trust and many of the others attending the symposium saw merit in reconvening the event around two years after the initial symposium, to report on progress with management, indicator monitoring, scientific understanding and other matters. We support that suggestion.

In terms of report format it is important that readers note the following:

- All authors were provided with 'briefs of work' and were requested to contextualise their work with that contained within the Taylor (1996) report on the lake—this was more easily achievable for some than others. Given some lack of consistency between symposium presentations and final papers it is our intention that a revised set of agreed indicators will be considered and included in any follow-up symposium and associated reports—some considerable work will be required in some areas to achieve this objective;
- Only the wildlife and integration papers included in this report have been formally peer reviewed; and
- All other papers have been standardised and style edited-some changes have been suggested by the report editors and made by the paper authors.

Finally, an attempt has been made to present the papers in a logical sequence of 11 chapters: chapter 1 sets the scene; chapters 2-7 cover the biophysical science dimensions (groundwater, water quality, native vegetation, native fisheries, trout, wildlife); chapters 8-10 deal with the human dimensions (Ngāi Tahu, recreation, economics); and chapter 11 deals with integration of the findings from the previous chapters and setting the scene for future management.

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[1] Note that the Geographic Place Names Board has defined the name as Lake Ellesmere (Te Waihora). It is not our intention to debate the nomenclature, but rather to put the focus where we consider it should lie, within the lake's initial historical and cultural context for indigenous Maori.


SHELLEY McMURTRIE

02

GROUNDWATER and the ‘living lake’

HOWARD R. WILLIAMS Environment Canterbury

Surface water inflow to Te Waihora/Lake Ellesmere is largely sourced from groundwater flowing into its catchment. In turn, this groundwater is sourced from both rainfall recharge and seepage from rivers. A marked decrease in groundwater levels over the last decade has been caused by drier than average conditions, in combination with large increases in groundwater abstraction. The decrease in groundwater levels induced a corresponding decrease in spring-fed stream flows that enter the lake. Planned adaptive management of the groundwater resources in the Te Waihora/Lake Ellesmere catchment aims to balance the needs of the lake with intense groundwater development and potential adverse effects of climate change.

2.1 Introduction

At least a millennium ago, the un-named body of water later to be called 'Te Waihora/Lake Ellesmere', had variously been: a major discharge point for the Waimakariri River; a relatively quiet tidal estuary; and a freshwater lake. Such major changes in its character were caused by the chaotic migration of the Waimakariri River across its braid plain. Sometimes the river discharged south of Banks Peninsula, sometimes north. Currently, Te Waihora/Lake Ellesmere is a brackish bar-type lagoon: it has not always been so.

Over the last few thousand years at least, the lake has been largely fed by water that has spent much of its time underground-groundwater. Figure 1 depicts a schematic view of the catchment water inputs and outputs that provide water to Te Waihora/Lake Ellesmere.

Except during periods of persistent rain such as occurred during the winters of 2006 and 2008, or during the wet periods of the mid-1990s, nearly all of the water entering Waihora/Ellesmere is derived from the groundwater system that underlies the gravel-dominated strata of the Central Plains. The groundwater system is fed from two sources of recharge: rainfall incident on the plains; and subterranean seepage from the Rakaia and Waimakariri rivers. For short bursts, generally during winter, discharge into Te Waihora/Lake Ellesmere is supplemented by surface flow derived from the foothills distributed north of a line from the Rakaia Gorge to Darfield (Figure 1). This brief review of recent research describes how and why Te Waihora/Lake Ellesmere is so dependent upon groundwater, and what is being done to ensure that this dependency is fed sustainably. To aid in an under-

Photo ***A general view of the lake, looking south.*** *Photography* ***Shelley McMurtrie.***

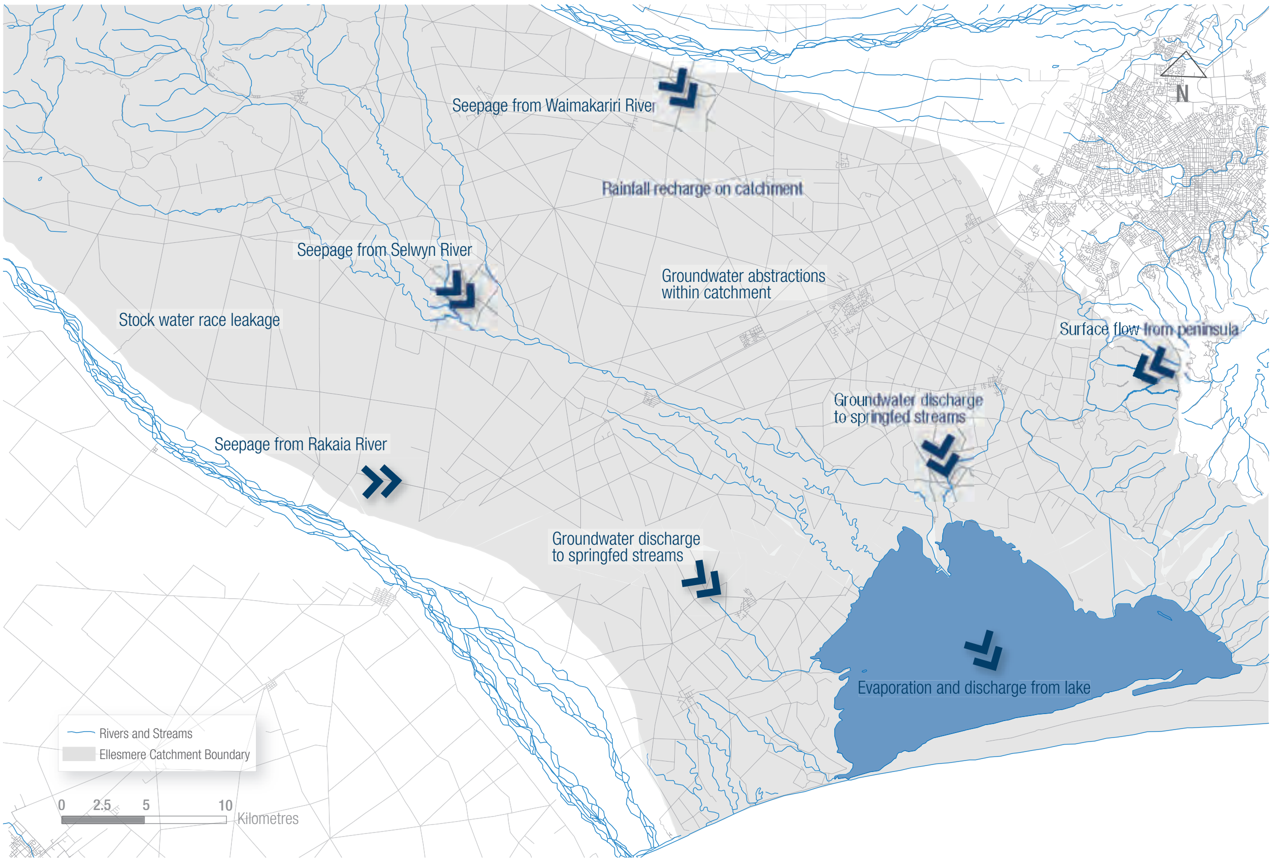

FIGURE 1. The Te Waihora/Lake Ellesmere catchment, showing schematic water inputs and outputs (Modified from Figure 6.17 in Taylor 1996).

standing of this groundwater system, I first briefly describe the last two million years of inter-related climate and geology.

2.2 Past climate of the catchment

The Canterbury Plains were formed during cold and generally wet stages alternating with warmer and drier periods typical of the Pleistocene glaciations world-wide. To the west of what is now Te Waihora/ Lake Ellesmere, a rapidly rising land mass, the Southern Alps, stored much snow and caused much rain to fall. During periods of melting, huge masses of water were released, bringing with it in the order of 10,000 cubic kilometres of gravel, mixed with sand and silt. The Canterbury Plains comprise material that can only have been transported and deposited during major flood events such as are not, fortunately, experienced today. In these wet periods, not only were the plains decorated with a tracery of laterally migrating braided rivers, but groundwater levels were near surface.

As the glacial conditions gradually ameliorated to our dry and warm current climate, far less rain and snow fell, with the result that the major rivers ceased to transport large quantities of material, and groundwater levels gradually dropped. The reduction in gravel transport and deposition meant that lateral migration of the braided rivers became less common, and the coastline ceased to be eastward-prograding. Currently at the coastline, processes of long shore drift, and recession of the coastline have become important (Leckie 2003), while inland, rivers have cut down into their deposits.

2.3 Geology of the catchment

The Canterbury Plains comprise a series of large coalescing fluvio-glacial fans built by the main stem rivers (Rangitata, Ashburton, Rakaia and Waimakariri). During successive glaciations when glaciers partly occupied the inland valleys and extended to the eastern foothills, great quantities of detritus eroded from rapidly rising mountains. Gravel, with sand and silt material, was transported eastwards and literally dumped, without sorting, to form the fans of gravel-dominated strata that extend beyond the present day coastline (Figure 2).

Superimposed on the regional architecture of the coalescing fans created by the major rivers, are inter-fan depressions occupied by smaller-scale fans of reworked gravels. The inter-fan Selwyn River occupies the depression between the major overlapping fans of the Rakaia and Waimakariri rivers and consists of reworked gravels exhibiting a more open texture than the fluvio-glacial gravels associated with the adjacent fans (Anderson 1994; Brown 2001; Brown and Wilson 1988; Wilson 1989).

The thickness of gravels is variable, ranging from over 300 m to greater than 600 m (Figure 2). These gravels contain a finite though renewable resource of groundwater which is utilised by means of wells, with a maximum well depth currently at 240 m in the Te Pirita area.

It is probable that groundwater in the uppermost gravel strata discharges into the marine environment, all others are probably pinched out laterally. The significance of this is that groundwater discharge from the groundwater system to the marine environment is likely to be only through these uppermost strata (Figure 2). Gravel-dominated strata in the coastal zone are separated by fine-grained sediment such as silt as shown in Figure 2.

Although there has been a tradition of separating out the various gravel strata in the coastal zone into ‘aquifers’, inland, these are not discrete entities but are zones of preferred well screening reflecting the interplay of a number of geological characteristics. Over most of the Canterbury plains, the gravels cannot be divided up into true aquifers because they cannot be geologically mapped as such and are not separated by discrete lithological zones of contrasting material ‘aquitards’. Well logs do not indicate long-distance correlation of strata from well to well. Indeed, away from the coastal portion of the zone, the concept of a layered stratigraphy is unsupported by drilling records. The groundwater system is simply contained in a large set of overlapping and interconnected, elongate lens-shaped structures of relatively permeable gravel set in a matrix of less permeable gravel, sand and silt. Modelling of braid-plain gravel fans has shown that the build up and preservation of the gravel-dominated layers results in a heterogeneous and anisotropic mass that is variably saturated with groundwater.

2.4 Groundwater hydrology of the catchment

In this section the sources of recharge to groundwater, its passage through the gravels, and its eventual discharge are described.

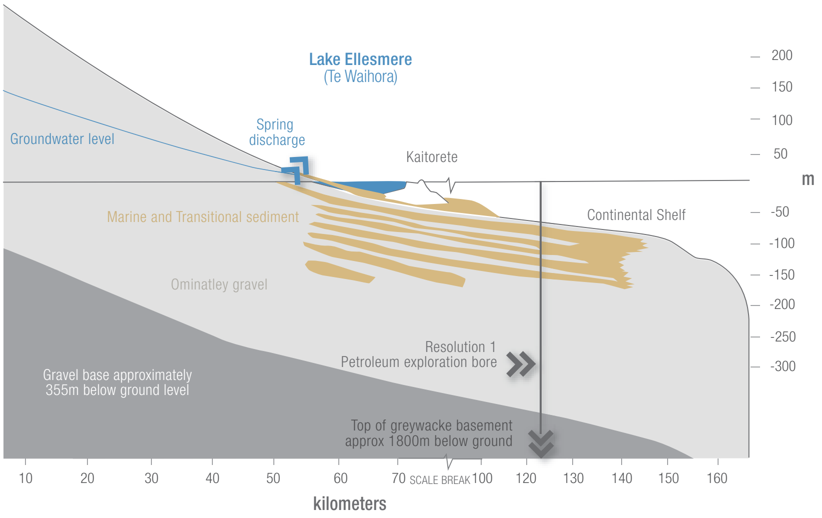

FIGURE 2. Geological cross-section showing the schematic relationships between strata, spring discharge, Te Waihora/Lake Ellesmere and Kaitorete barrier (based on Ettema 2005).

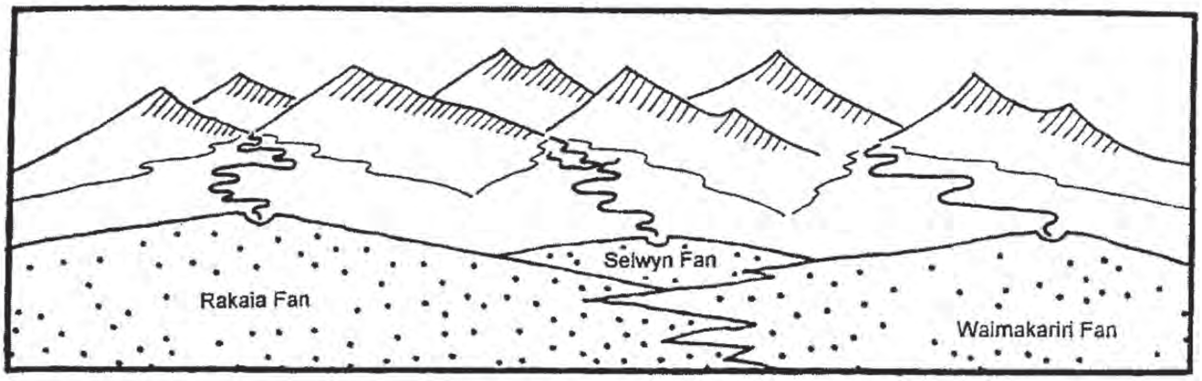

FIGURE 3. A simplified and schematic oblique view of the fan deposits associated with the three rivers in and bordering the catchment, looking towards the foothills to the northeast.

Recharge sources

Groundwater in much of the catchment represents recharge from rainfall, and seepage from the Rakaia and Waimakariri rivers, from irrigation races, and return water from irrigated land. Rainfall falling on the plains portion of the catchment largely disappears and forms groundwater. Rainfall falling in the foothills discharges to the Selwyn and Hororata rivers.

Observations in the upper Selwyn River area indicate that the groundwater and surface water resources interact (Taylor 1996). There is a partitioning of the entire water resource between the Selwyn River and its tributaries, and the groundwater system. Water may be lost from one watercourse by seepage into groundwater, that then emerges in an adjacent tributary. For example, flow is lost from the upper reaches of the Selwyn River, but flow lines determined from detailed water levels, and water chemistry, indicate that this water emerges as springs feeding into the Hororata River (Vincent 2005). In turn, both these rivers lose flow into the groundwater system further south, reappearing again in the spring-fed streams (Gabites and Williams 2007; McKerchar & Schmidt 2007). In effect, the quantum of losses in the upper part of the Selwyn catchment is approximately the same as the gains (spring discharges) at the bottom of the catchment.

Along the centre of the catchment, the Selwyn River provides recharge to groundwater with the result that surface flow in that river generally disappears. Significantly, most, if not all of this groundwater reappears in spring-fed streams near to the coast.

Along the south-western and northern boundaries of the catchment, the major alpine rives allow seepage of part of their flow into the groundwater system. For example, in the Little Rakaia area and the elongate riparian zone adjacent to the Rakaia River, a major proportion of the groundwater is derived by seepage from the Rakaia River. Similarly, seepage from the Waimakariri River flows east towards Christchurch and south, around the western margin of Banks Peninsula, towards the lake.

Hydrogeology of the catchment

This section describes the groundwater flow directions in the catchment. Within the catchment, groundwater flow is from the higher ground in the northwest, towards the coast. A map of groundwater contours measured in the uppermost strata is presented in Figure 4.

Groundwater flow moves at right angles to piezometric contours. The groundwater piezometric contours also indicate that losses from surface water flow to groundwater are evident from the Rakaia River into the Little Rakaia area. In contrast, groundwater flow resulting from rainfall recharge results in groundwater contours that are generally parallel with topographic contours, and with the coast. South west of Te Waihora/Lake Ellesmere, groundwater flows either towards the lake, or towards the sea.

In addition to groundwater flow within the gravel strata, there is evidence of vertical flow between strata of differing depths. For example, in the inland plains such as in the Te Pirita, and Dunsandel areas, a downward piezometric gradient exists, with the result that groundwater flows downwards, from gravel into underlying gravel. Measurements of water pressures in wells indicates that groundwater levels (pressures) become progressively deeper (lower) with depth, though this variation in pressure seems to disappear below about 100 m. Downwards groundwater flow, from overlying strata into underlying ones, represents the mechanism whereby infiltrated rainfall and river recharge penetrate into the deeper strata.

Towards the coast, at the inland margin of where spring-fed streams appear, the vertical groundwater pressure gradient becomes upwards, with higher pressures in deeper strata. As a result, groundwater flow is both seaward and upwards, towards the land surface. The presence of thin and discontinuous confining layers overlying and between the gravels in this coastal zone, and the seawards pinching out of deeper gravel strata, help maintain this pressure gradient.

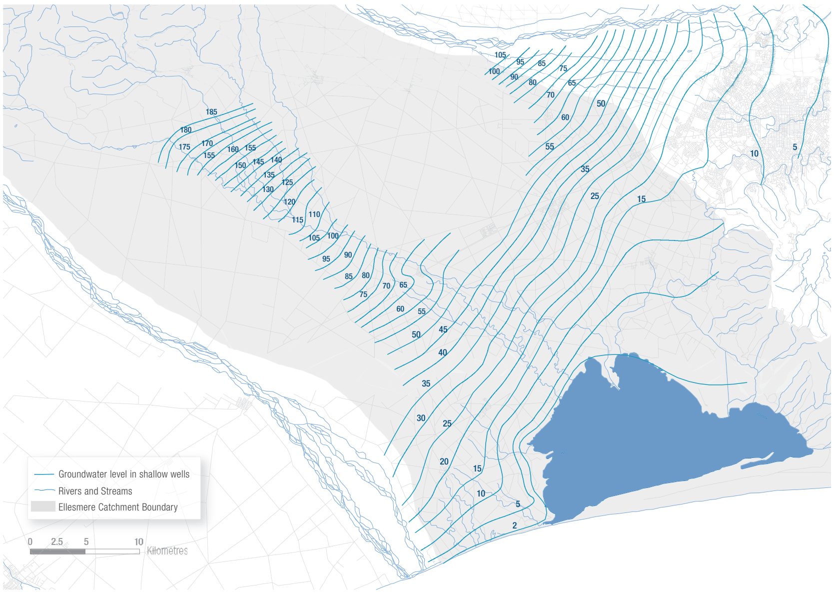

FIGURE 4. Groundwater contours (metres above mean sea level) within the shallowest water-bearing strata in the catchment.

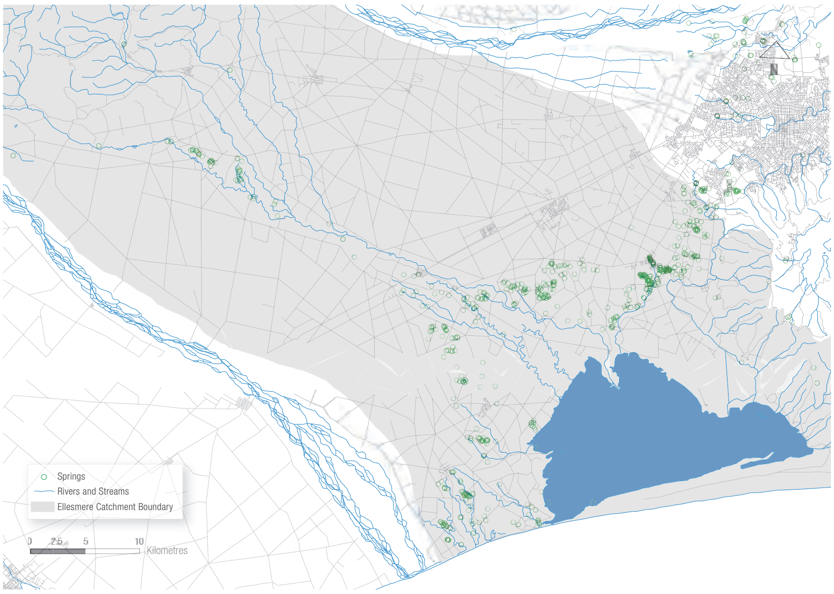

FIGURE 5. Spring distribution in the catchment.

Photo ***Lake flats taken at low water level, showing deposition of fine-grained sediment and encroaching vegetation.*** *Photography* ***Shelley McMurtrie.***

This pressure difference, driving groundwater flow and maintaining groundwater levels, explains the distribution of discrete artesian and depression springs that feed many of the lowland streams. The spatial distribution of artesian and depression springs is shown in Figure 5.

Flow discharges from both artesian and depression springs are sensitive to groundwater levels. Springs and dispersed seepage of groundwater occur also within the lake (Ettema & Moore 1995).

The artesian nature of the coastal portion of the groundwater system is illustratevd by the occurrence of flowing artesian wells in the areas around the lake, and of springs in the lake. Maintenance of this artesian pressure is significant in keeping the marine saltwater / groundwater interface at bay. Temporal variation in this hydraulic pressure controls flow in the spring-fed streams.

2.5 Water budget

The most recent estimates of the input and outputs of water to the catchment are those produced by White (2008), using data largely derived from Horrell (2006), and updating those in Taylor (1996). The water budget in Table 1 serves to illustrate the general magnitude and uncertainty of these variables.

Although some terms in the water budget such as long-term means of rainfall recharge and use can be estimated reasonably, the discharge from the major alpine rivers is not well quantified, nor is the groundwater discharge direct to the ocean.

Obtaining better estimates of the major inflows from the alpine rivers, and the outflow of groundwater direct to the ocean are necessary to advance understanding of the hydrogeology of the catchment.

2.6 Groundwater levels and trends

In this review I briefly describe groundwater levels from three geographical areas: inland plains; mid-plains; and the coastal area. These three areas reflect broad topographic, rainfall and groundwater characteristics. Similar descriptions are to be found in the

TABLE 1. **Te Waihora/Lake Ellesmere catchment water budget (based on Table 5.10 in White 2008).**

Component	Te Waihora/Lake Ellesmere catchment (m^3/s)
Land surface recharge	23.8
Rainfall on Te Waihora/Lake Ellesmere	3.6
Recharge from Rakaia River	3 to 11
Recharge from Selwyn River	1.5 to 3.5
Recharge from Waimakariri River	3.5 to 4
Recharge from Banks Peninsula streams	0.3
Sea water inflow to lake	3.5
Stock race leakage	1
Evaporation from Te Waihora/Lake Ellesmere	6.1
Surface water discharge to sea	12.9
Discharge across spit	1 to 5.6
Groundwater use	11.3
Surface water use	0.3
Outflow from catchment to Little Rakaia zone	2.1 to 2.8
Outflow from catchment to Christchurch-West Melton zone	1
Sum of inflows	40.2 to 50.7
Sum of outflows	34.7 to 40
Off-shore groundwater discharge	0.2 to 16
Groundwater discharge to spring-fed streams	12
Groundwater discharge direct to Te Waihora/Lake Ellesmere	0.1

annual reports entitled: 'State of the water resources at the end of winter' regularly published by Environment Canterbury (e.g. Martin and Williams 2007).

Inland plains

Groundwater levels in wells in the inland plains area are close to or at minimum levels. Figure 6 presents details of water levels from six wells reflecting different strata and well depths. Groundwater levels below seasonal and annual means are evident in all of these wells, as they are in other wells in this area.

Few inland plains wells have relatively long periods of data available. Groundwater levels in these wells were high during the relatively wet years of the 1970s, and low in the dry mid-1980s. A seasonal pattern is evident since 1997, an increasing summer irrigation-induced groundwater drawdown (saw-tooth pattern). This is particularly evident, not only in the pumped well L36/0023, and but also in the Te Pirita observation bores L36/1157 and L36/1226 (Figure 6). The declining saw-tooth pattern shows that over the last 12 years, seasonal (winter) recovery has been insufficient to allow recovery of groundwater levels. In contrast, the Darfield well L35/0163 shows less of a declining trend, perhaps due to its proximity to the Waimakariri River.

The Te Pirita wells have a relatively short length of record, only being installed in the late 1990s when irrigation first developed in the area. These wells have previously been compared to a well at Greendale, L36/0092, which has a record dating back to the early 1950s. Figure 6 compares groundwater levels in the Te Pirita wells to L36/0092, a well whose water levels originally responded to climate change stresses, but are now increasingly affected by the cumulative effects of groundwater abstraction. Note in Figure 6 that deeper wells generally have lower groundwater levels.

There is a general correspondence in groundwater levels between the two Te Pirita wells (L36/1226 and L36/1157) and those in L36/0092. The two Te Pirita wells show marked progressively lower summer groundwater levels. In addition, winter levels are also lower each year, especially over the last six years.

Results from rainfall-evapo-transpiration-soil moisture models to calculate rainfall recharge, in association with eigen modelling (Bidwell 2003), indicate that the low winter recharge is in large part responsible for these low groundwater levels but that abstraction is compounding the problem. The eigen modelling has allowed robust simulation of groundwater levels and discharges based on a combination of climatic input and estimated groundwater abstraction data (Williams et al. 2008).

Mid plains

Groundwater levels from four wells located within the mid-plains area are displayed in Figure 7. Note in Figure 7 that there is less variation in general groundwater levels between wells of different depth.

Two of these wells have a monitoring record dating back to the early 1950s. Three wells, M36/0255, M36/0183 and L36/0142 illustrate similar trends from the 1970s. The pattern of groundwater levels in these wells progressively changes from about 1987, becoming more seasonally variable, especially in well L36/0181.

The seasonal pattern of groundwater levels in wells within and down-gradient of the North Bank irrigation scheme, such as L36/0258, changes radically from about 1987 as a result of irrigation discharges in the scheme. Groundwater in the vicinity of this well now enjoys extra recharge in summer from border dyke irrigation, leading to higher summer groundwater levels than those in winter. This effect is illustrated by the relatively high levels in the last few years, as well as the seasonal 'saw-tooth' nature of the variation in water levels, even in wells not showing localised drawdown interference effects.

Groundwater levels in the vicinity of well L36/0181 have become increasingly affected by irrigation pumping, representing an interference effect, with increasing summer drawdowns evident in the record since the late 1990s, combined with a decline in winter levels. Well L36/0142 does not indicate any clear-cut direct interference effect but there is an indication of progressively lower groundwater levels in summer in recent years.

Coastal groundwater levels

The seasonal range of groundwater levels in wells in the coastal area is much less than in wells elsewhere in the allocation zone due to its proximity to the coast, which provides a constant head boundary that moderates seasonal and climatic changes in water level. Note in Figure 8 that deeper wells tend to have higher groundwater levels. For example, some wells in the confined part of the zone exhibit positive artesian pressures (e.g. well M36/0355 in Figure 8).

In the coastal Te Waihora/Lake Ellesmere region, there is no consistent pattern of groundwater level (Figure 7) even though groundwater monitoring records for wells L37/0451, M36/0338 and M37/0010 extend back to the early 1950s.

Groundwater levels in well M36/0338 at Brookside, adjacent to the Irwell River, are strongly correlated with flows in that river. The seasonal range of water levels has increased in this well in recent years, from around 1 m to over 3 m. Prior to 1999, groundwater levels in M36/0338 were rarely lower than 3 m below ground (occurrences in the early 1970s and mid 1980s), but since then have regularly been lower. These low groundwater levels occur in late summer to early autumn and reflect increased abstraction locally and regionally.

Well L37/0451 is located within the Little Rakaia riparian area, adjacent to the north bank of the Rakaia River. Groundwater in this well is influenced by recharge from the Rakaia River, and particularly by the position of actively flowing braids within the Rakaia River. If the North Branch of the Rakaia River is active, groundwater levels will be higher in this well, and vice versa. This well illustrates the effects of the Rakaia River on the groundwater system adjacent to it.

Well M36/0355 is located at Doyleston, and is screened in a relatively deep aquifer. This well has a shorter period of monitoring record, and shows that the magnitude of summer seasonal drawdowns, caused by groundwater abstraction, is increasing each year, so that the range between summer and winter is now around 6 m, compared to around 2 m in the early 1990s. In the winter months this is a flowing artesian well, as shown by a water level above ground level. However, it ceases to flow in the summer when irrigation induces a regional lowering of groundwater level.

Photo ***Selwyn River at Coes Ford, looking upstream in March 2009, flow 300 L/s, half minimum flow.***
Photography ***Howard Williams.***

Well M37/0010, near Taumutu, has a very small range of water levels because it is close to the coast. Levels generally range from 2.5 m to 3.5 m below ground. While recent groundwater levels (since 2001) have been low, they are not lower than they have been historically.

Coastal wells, like those described in the inland and mid-plains areas, show evidence of the 'saw-tooth' seasonal decline and recovery of groundwater levels.

To conclude this section, it is clear that whilst many ECan observation wells are illustrating larger summer season declines than historically, in many wells the winter recovery levels are also declining. The only part of the catchment where this is not occurring is in the costal zone, where winter levels have remained relatively constant due to the fact that groundwater levels cannot rise further without inducing increased spring activity. In effect, the winter levels are capped, with the excess released as discharge to the lake.

2.7 Groundwater surface water interaction

Hydrogeologists generally acknowledge a relationship between local groundwater levels and spring flows. When groundwater levels or artesian pressures are high, spring flows are at a maximum, and vice versa. Such a relationship has been observed in this part of Canterbury and is continually monitored (Williams and Aitchison-Earl 2006). This section describes examples of this relationship for two spring-fed streams that occur along the northern edge of Te Waihora/Lake Ellesmere.

Springs cluster around the headwaters of many of the lowland streams around the lake. Except during protracted wet weather, these streams are generally fed by these springs. Along with groundwater abstraction, these streams form a major component of discharge from the groundwater system as a whole.

The relationships between groundwater levels and surface flows in the spring-fed

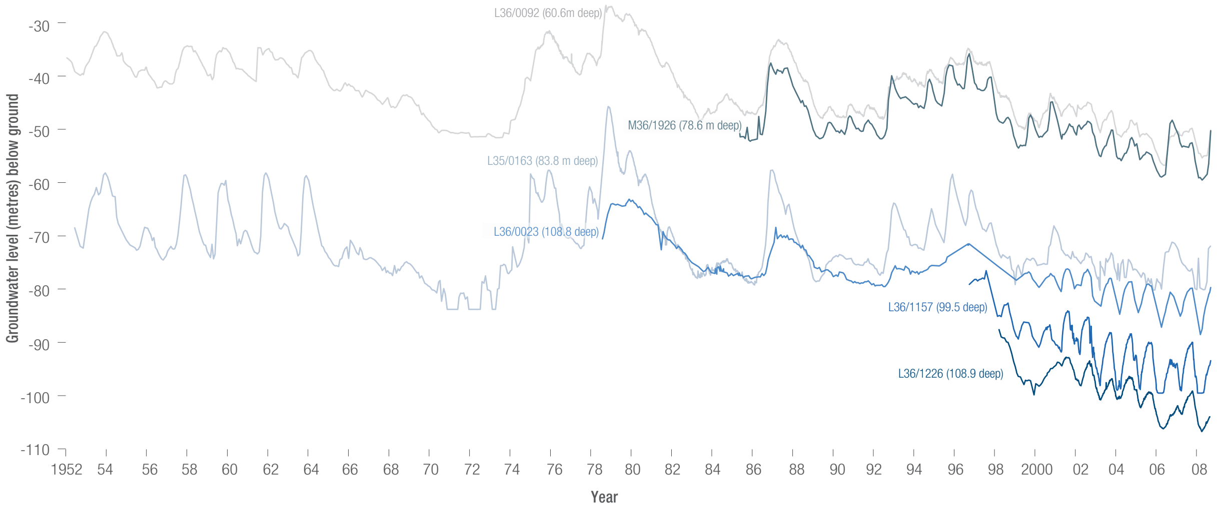

FIGURE 6. Groundwater levels and trends in six inland plains wells.

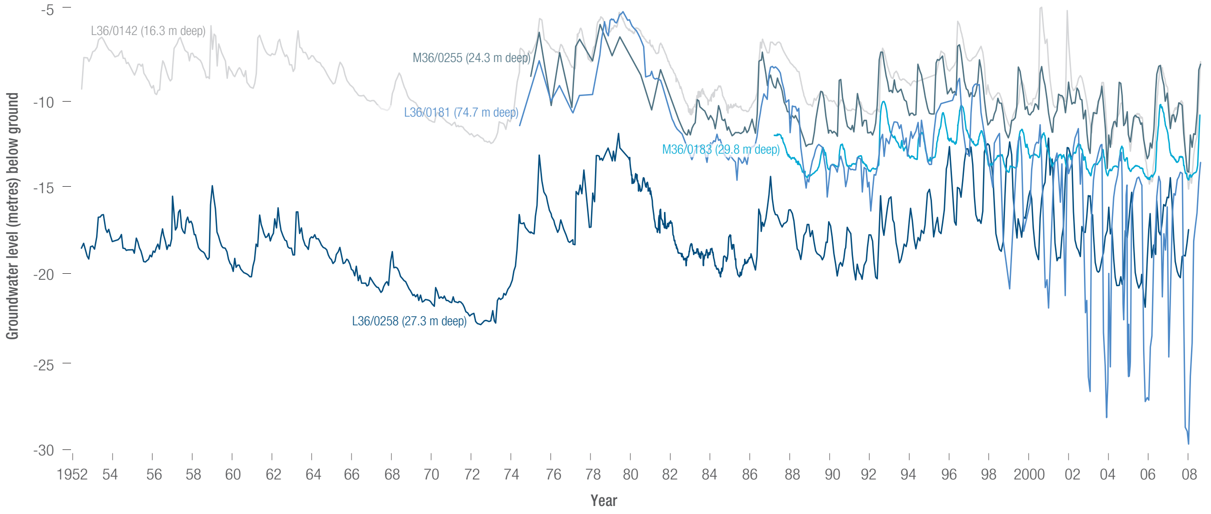

FIGURE 7. Groundwater levels and trends in mid-plains wells.

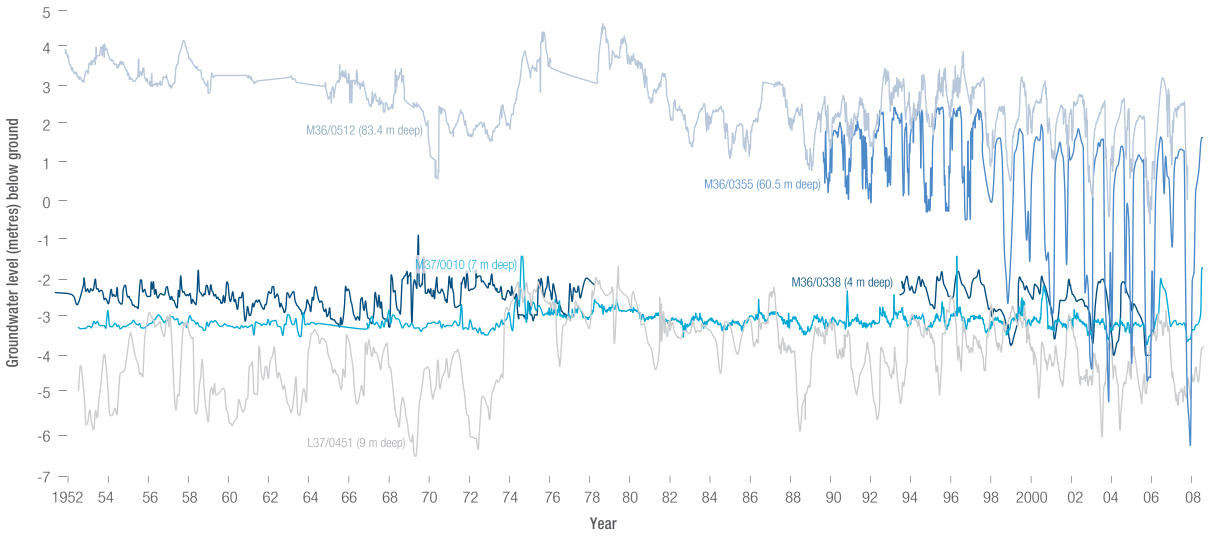

FIGURE 8. Groundwater levels and trends in coastal plains wells.

streams has been analysed by Williams and Aitchison-Earl (2006). They found that there was a good correlation between the flow in a spring-fed stream and the local groundwater levels in wells (Figures 9 & 10).

Monitoring has shown that the Irwell River can be expected to be dry when groundwater levels are deeper than 3 m below ground level in well M36/0338 (Figure 9). The frequency of the Irwell being dry at The Lake Road has increased in recent years, with the river dry for extended periods in 1998, 1999, 2001, 2003 to 2008. Groundwater levels in M36/0338 display a decreasing trend, with levels becoming lower in late summer since 1998.

Surface flow in Harts Creek also demonstrates a relationship with groundwater in the upstream well L36/0142, as shown in Figure 10. Since 2002, when groundwater levels in L36/0142 have been consistently low, surface flow in Harts Creek has regularly fallen below the statutory minimum flow of 1000 L/s.

Lowered flows in spring-fed streams correlate with observations on the progressive drying up of springs and seeps, and the regional lowering of groundwater levels. As a consequence, monitored wetted length and breadth of rivers has also decreased, with consequent ecological effects.

To conclude this section, it is worthwhile stating that the intimate relationship between groundwater levels and spring-fed stream flows, means that in order to protect the inflows to the lake, management of groundwater levels is required.

2.8 State of the water resource

The preceding sections on groundwater levels and trends, and the relationship between groundwater and surface water allow the following statements.

Whilst climate is the main driver for the time-series variation in groundwater levels, and as a consequence, the discharge from the aquifer system, intensification of existing groundwater abstraction without appropriate management of groundwater abstraction will likely lower groundwater levels and stream discharges.

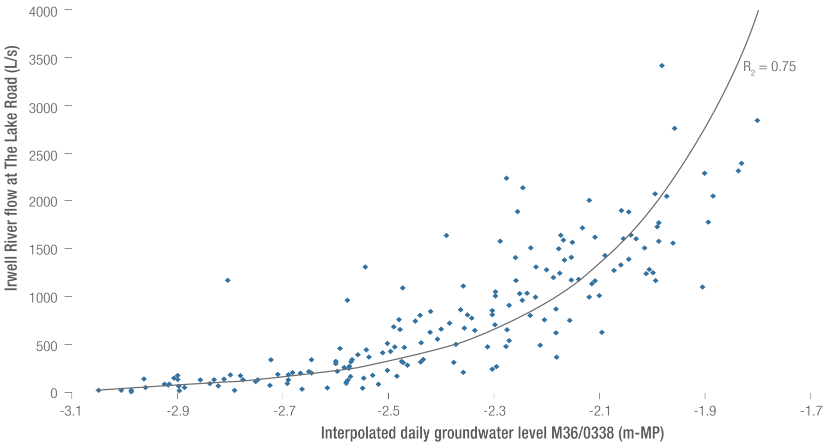

FIGURE 9. Relationship between groundwater level in well and flow in the Irwell River.

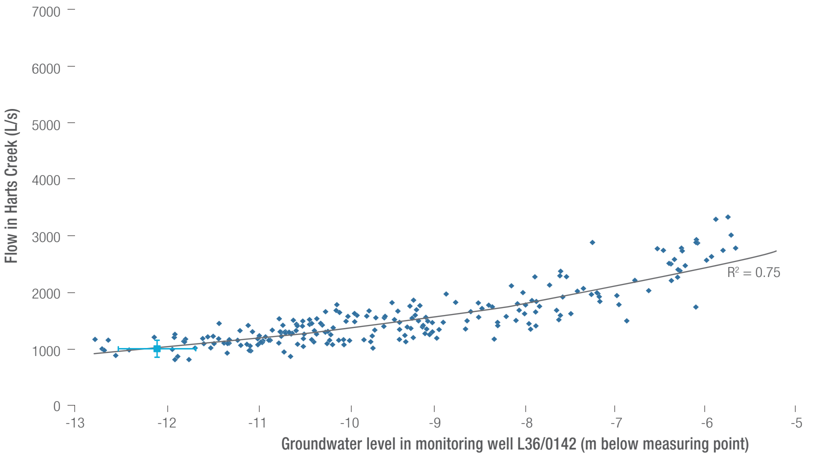

FIGURE 10. Relationship between groundwater level in well L36/0142 and flow in Harts Creek (blue cross is standard error).

Photo ***Harts Creek at the Environment Canterbury flow monitoring station, Timberyard Point Road bridge, March 2009, at about minimum flow of 1000 L/s.*** *Photography* ***Howard Williams.***

Abstracted volumes of groundwater by consent holders is largely unmanaged at present. The institution of metering of takes in the Rakaia-Selwyn allocation zone will aid understanding of the water budget that in turn will inform a groundwater management method.

2.9 Groundwater management

In 2004, Environment Canterbury instituted groundwater allocation zones with specific allocation limits (Aitchison-Earl et al. 2004). Within each groundwater allocation zone a groundwater budget was prepared. The allocation limits largely related to the quantum of dryland surface recharge in each zone. The limits and the boundaries of zones underwent some change as new data were forthcoming, until the limits were set more formally in Variation 4 of the Proposed Canterbury Natural Resources Regional Plan.

The Te Waihora/Lake Ellesmere catchment lies within the greater part of two allocation zones: Rakaia-Selwyn and Selwyn-Waimakariri. The dependency of Te Waihora/Lake Ellesmere on groundwater-sourced input has resulted in Environment Canterbury implementing a 'Restorative Programme for Lowland Streams' (RPLS). The RPLS involves review of over 600 consents in the Rakaia-Selwyn zone (ECan 2007). The programme resulted from recognition that the combination of climate and abstraction was causing adverse effects on groundwater levels that in turn adversely affected the spring-fed stream discharge. The review is on-going, and one of its aspects is the introduction of adaptive management of groundwater resources (Williams et al. 2008) whereby consented abstraction of groundwater will be tailored to supply, as determined from knowledge of the recharge to the aquifer system.

Whilst the dependency of the lake on the groundwater system in its catchment cannot be reduced, it is to be hoped that by managing groundwater abstractions during times when the inputs to the aquifer system are low, the output from the system to the lake will be maintained at a level that ensures protection of Te Waihora/Lake Ellesmere.

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Photo ***Groundwater being used to irrigate pasture. "Whilst there are significant economic and social benefits accruing from irrigated agriculture, a balance needs to be maintained between these and the complementary adverse environmental effects of abstraction on the hydrological system, including Te Waihora".*** *Photography* ***Shutterstock.***

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SHIRLEY HAYWARD

03

WATER QUALITY in the Ellesmere catchment

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The water quality of Te Waihora/Lake Ellesmere is one of high nutrient and sediment concentrations, consequently with high phytoplankton biomass and low water clarity. However, despite its highly enriched state, Te Waihora/Lake Ellesmere does not exhibit many of the detrimental characteristics of a highly enriched lake, such as algal blooms, deoxygenation and fish kills. Furthermore, it supports abundant fish and bird communities.The quality of the lake tributaries reflect the intensive land use surrounding them, with elevated nutrients and bacteria found in many sites. Monitoring of the lake over the past 15 years shows little change in nutrient concentrations and phytoplankton biomass but it has shown a decline in water clarity. The salinity of the lake has also shown a decrease in the past 15 years. Lake level management is an important driver of many components of the lake, and particularly influences lake salinity. The varying salinity across the lake is a key factor in the lakes' diversity. Being a lowland lake, it not only receives inputs within the immediate vicinity of the lake but also from the wider catchment across the Plains up to the foothills. This has implications for the scale of management issues. Riparian protection around the lake margin and tributaries will greatly help reduce some contaminant inputs such as sediment and phosphorus, but catchment wide nutrient and water allocation management will be needed to reduce nitrates and improve freshwater inflows to the lake.

3.1 Introduction

Environment Canterbury's water quality monitoring programme for the lake and tributaries has been carried out routinely since 1993, with occasional monitoring from 1973 (Taylor 1996). This report discusses the current state and changes in lake water quality since 1993. Potential drivers for these changes are suggested along with some land use changes in the region since the 1990s. Comparisons with other Canterbury coastal lakes are illustrated.

Four lake sites and nine inflowing rivers and streams have been sampled (Figure 1). Tests for nutrients (nitrogen and phosphorus), chlorophyll a, clarity, salinity, oxygen and suspended solids have been carried out in addition to microbial analyses.

State and trends in lake water quality

The current state of water quality in Te Waihora/Lake Ellesmere and tributaries is based on the five years of monthly data (July 2002-June 2007) for the four monitoring sites. Comparison to other Canterbury coastal lakes helps put a context around interpretation of the data.

Trend analyses is based on monthly data for the four lake sites over the past 14 years (1993 to 2007). Table 1 summarises trends detected for the main water quality determinands.

Microbial quality

Microbial quality is both a human and stock health issue and affects the suitability of water for domestic and stock drinking water supply and for contact recreation. Concentrations of faccal indicator bacteria collected from the four lake sites indicate that waters were generally within the acceptable limits for contact recreation (Figure 2).

Drivers of microbial quality include inputs of faecal material from birdlife, grazing stock along the lake edge and stream inputs

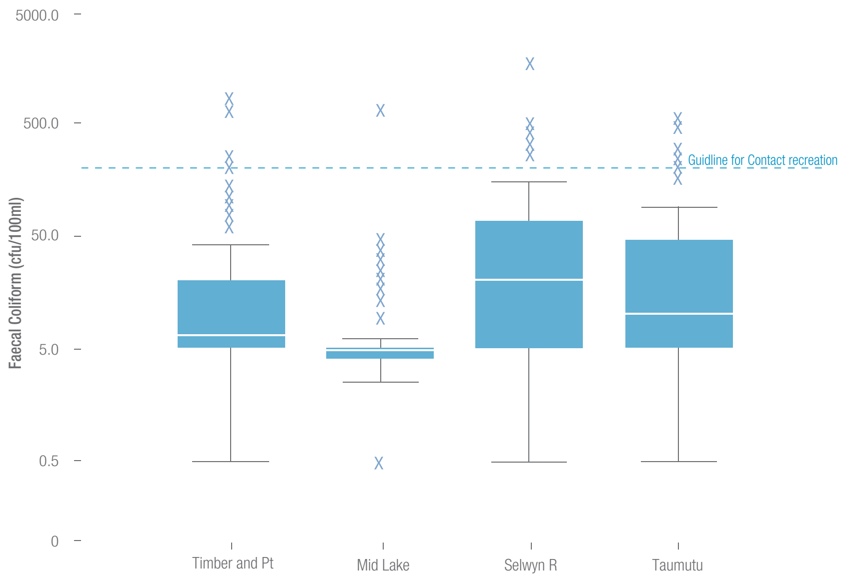

FIGURE 2. Faecal coliform concentrations in four sites on Te Waihora/Lake Ellesmere (2002-2007).

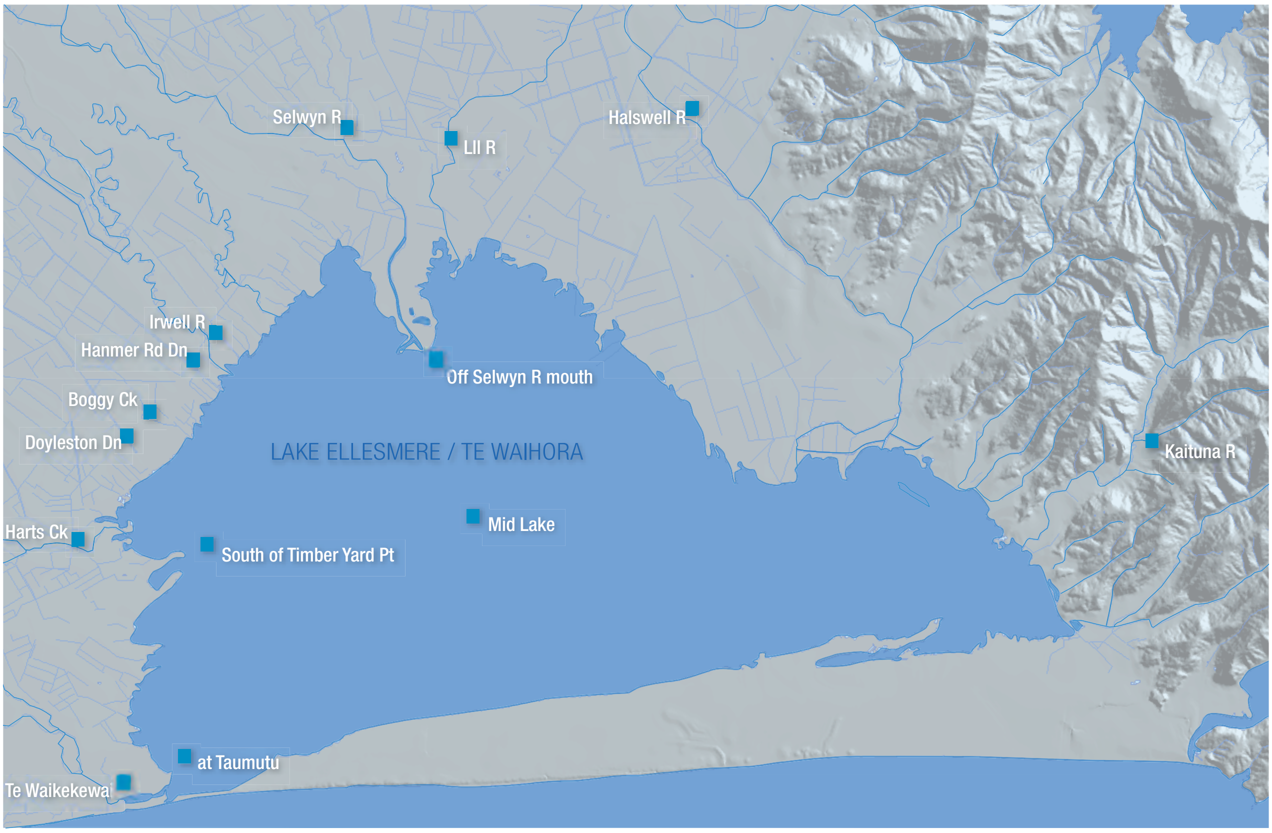

FIGURE 1. Location of water quality sampling sites on Te Waihora/Lake Ellesmere and the main tributaries. Base Map sourced from ECan.

from grazing stock, domestic animals and effluent disposal (to land).

3.2 Nutrients

Dissolved inorganic nitrogen (DIN) concentations at all four sites in Te Waihora/Lake Ellesmere showed a decrease in concentration over the last 14 years but dissolved reactive phosphorus (DRP) had increased at all sites (Table 1). The decrease in nitrogen concentrations could be explained by the decrease in DIN loading from tributaries (see below), but the increase in soluble phosphorus is in contrast to a decrease in phosphorus loadings from tributaries (Table 2).

There are less consistent trends in total nutrient concentrations (Table 1). Total nitrogen concentrations decreased at two sites, but no trends in total phosphorus concentrations were found. Total nitrogen and phosphorus concentrations are generally considered more relevant indicators of lake trophic status and include the dissolved and bioavailability nutrients plus nutrients attached to particles and contained within phytoplankton cells.

Total nitrogen concentrations from the four sites on Te Waihora/Lake Ellesmere were greater than those of other coastal lakes in Canterbury and generally fall into the hypertrophic classification (Figure 3). Total phosphorus concentrations were also generally higher (median) than the other coastal lakes, although Lake Forsyth/Wairewa and Wainono Lagoon also fall into the hypertrophic classification for TP (Figure 4). Drivers of the trophic state of the lake as a whole include nutrient inputs from tributary streams, groundwater and wildlife, and light availability-limited by suspended sediment and seasonal temperature. Current estimates of nutrient inputs of total phosphorus load to the lake are: 90% from tributaries, 6% from rainfall and 4% from birdlife. Total nitrogen loading estimated to arise from tributaries is 98%, rainfall 1% and direct ground water inputs 1%.

3.3 Phytoplankton biomass

Despite the decrease in nitrogen inputs, there has been no change in chlorophyll a in Te Waihora/Lake Ellesmere from 1993 to 2007 (Table 1). This suggests (as others have suggested) that nitrogen availability is not generally limiting to phytoplankton growth. However, there are indications it could be

TABLE 1. **Summary of statistically significant trends in water quality data collected from 1993 to 2007 for four sites on Te Waihora/Lake Ellesmere.**

	Timberyard	Mid lake	Off Selwyn	Taumutu
Dissolved oxygen (% saturation)	0	0	0	0
Suspended solids concentrations	0	0	0	+
Clarity (Secchi depth)	-	-	-	-
Salinity	-	-	-	-
Dissolved inorganic nitrogen (nitrate+nitrite+ammonia) (DIN)	-	-	-	-
Total nitrogen concentrations (TN)	-	0	-	0
Dissolved reactive phosphorus (DRP)	+	+	+	+
Total phosphorus concentrations (TP)	0	0	0	0
TN:TP ratio	-	-	-	-
Phytoplankton biomass (Chlorophyll a)	0	0	0	0
Faecal coliform bacteria	0	0	0	0

0 no statistically significant trend

- statistically significant trend of decreasing value

+ statistically significant trend of increasing value

TABLE 2. **Summary of statistically significant trends in tributary water quality data (concentration (Conc.) and load) collected from 1996 to 2007.**

		Kaituna R	Halswell R	LII R	Off Selwyn	Irwell R	Hanmer Rd Dn	Doyleston Dn	Harts Ck
Flow		0	-	-	-	-	-	-	-
Dissolved Inorganic Nitrogen	Conc.	0	-	-	+	-	+	-	+
	Load	0	-	-	-	-	0	-	-
Total Nitrogen	Conc.	-	-	-	+	-	+	-	+
	Load	0	-	-	-	-	0	-	-
Dissolved Reactive Phosphorus	Conc	0	+	-	+	0	+	+	+
	Load	0	0	-	-	-	-	0	0
Total Phosphorus	Conc.	0	0	-	0	0	0	0	-
	Load	0	-	-	-	-	-	-	-

0 no statistically significant trend

- statistically significant trend of decreasing value

+ statistically significant trend of increasing value limiting at times during periods of calm, warm weather and high lake levels. During this time low levels of suspended sediment may result in increased light penetration and therefore greater opportunity of phytoplankton growth (Hawes and Ward 1996, Hamilton 2008).

Phytoplankton biomass (measured as chlorophyll a) was overall higher in Te Waihora/Lake Ellesmere than in the other three coastal lakes from 1993 to 2007 (Figure 5). However, the annual maximum chlorophyll a was lower in Te Waihora/Lake Ellesmere than in Lake Forsyth/Wairewa where toxic algal blooms are more frequent (Figure 6).

There is some debate over the definition of the trophic status of the lake. Although Te Waihora/Lake Ellesmere has high nutrient and phytoplankton values that place it in the category of hypertrophic (extremely enriched), the lake does not exhibit many of the characteristics of such a classification, i.e., it does not regularly undergo severe oxygen depletion, nor does it produce unsightly or toxic algae blooms (unlike its neighbour, Lake Forsyth/Wairewa, which fits into the same trophic status and does routinely have toxic algae blooms, deoxygenation problems and occasional fish kills).

An important driver in phytoplankton growth is light availability which is driven by suspended sediments. While there does not appear to be any major changes in suspended solid concentrations, clarity (Secchi depth) has shown a consistent decreasing trend (Table 1). Lake level and climate are also significant factors in controlling phytoplankton production. The highest overall chlorophyll *a* values occurred during the 1998-99 drought, when lake levels were maintained at low levels because of high evaporation rates and low freshwater inputs. High water temperatures would have also been important in phytoplankton production.

3.4 Clarity

Visual clarity of the lake water, as measured by Secchi disk, is important for recreation and amenity values and ecologically for visual feeding of insects, fish and birds and for plant and algal growth. Figure 7 indicates that clarity is low and shows little variation throughout the lake although clarity has shown a consistent decreasing trend at all sites (Table 1).

Drivers of visual clarity, and its inverse turbidity, include phytoplankton biomass (driven by nutrients, light, temperature), suspended sediment (wind driven re-suspension of bed sediments) and sediment inputs (stream inflows, lakeshore erosion).

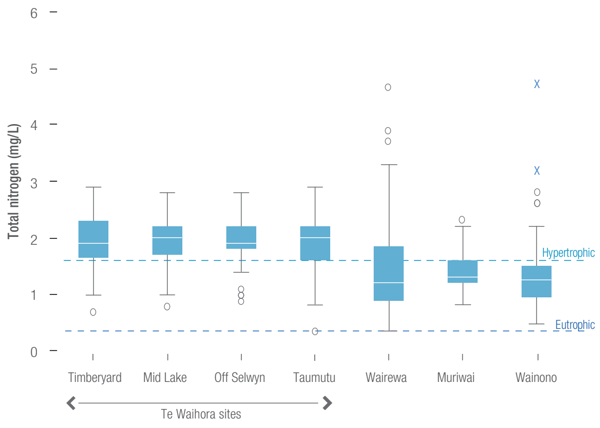

FIGURE 3. Total nitrogen concentrations in four sites on Te Waihora/Lake Ellesmere compared to other coastal lakes (2002–2007).

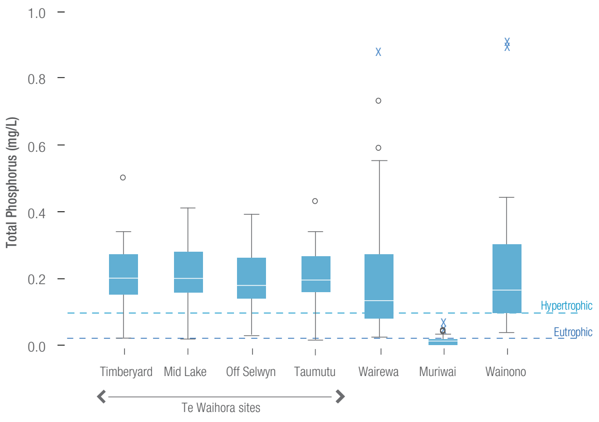

FIGURE 4. Total phosphorus concentrations in four sites on Te Waihora/Lake Ellesmere compared to other coastal lakes (2002–2007).

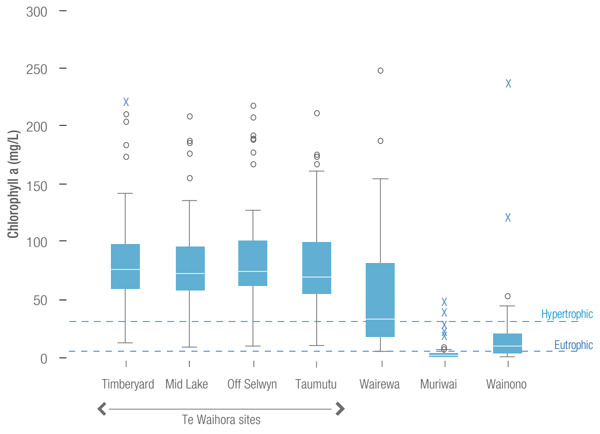

FIGURE 5. Chlorophyll a concentrations in four sites on Te Waihora/Lake Ellesmere compared to other coastal lakes (2002–2007).

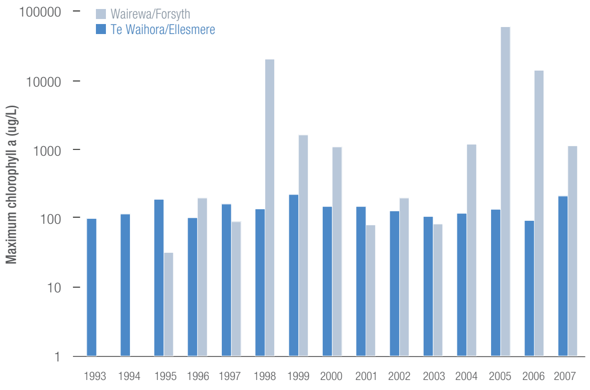

FIGURE 6. Annual maximum chlorophyll a in Te Waihora/Lake Ellesmere (mid lake site) and Lake Forsyth/Wairewa (January 1993–2007).

3.5 Salinity

The brackish nature of Te Waihora/Lake Ellesmere is a result of the mixing of sea water and fresh water inflows. Sea water inflows occur during lake openings and from waves overtopping the gravel bar. The salinity of the lake varies spatially and temporally throughout the lake and contributes to habitat diversity and therefore biotic diversity such as salt marshes and freshwater raupo beds.

There has been a significant decrease in salinity at all sites within Te Waihora/Lake Ellesmere which appears to be related to decrease in frequency of openings, overall lake levels (linked to decrease in freshwater inflows-both base flows and floods) and rates of evaporation (Figure 8). The highest annual average salinity occurred during the 1998/99 drought, when the frequency and duration of lake openings were low and the lake level remained unusually low because of high summer temperature and reduced freshwater inflows (Figure 8). Between 2002 and 2007 salinity in Te Waihora/Lake Ellesmere was generally higher than in Wairewa although the range was not as great (Figure 9).

Tributaries to the lake

Tributaries are valued in their own right for recreational, ecological and amenity values but they also have a major influence on the lake itself. Inflows come from about 40 rivers and streams, dominated by groundwater fed streams. Most streams are small and vulnerable to adjacent land use impacts as they flow across intensively farmed land. Trends (Table 2) in water quality include an overall reduction in nutrient loadings to the lake. This is driven primarily by reduction in flows over the past 10 years (Hayward 2007) rather than a reduction in instream nutrient concentrations. The exception is inputs from the Kaituna River, which has not shown any significant decrease in flows or nutrient loadings.

Most tributaries exceeded the contact recreation guideline for faecal coliforms (Figure 10). Faecal coliform concentrations in Boggy Creek and Doyleston Drain frequently exceeded the stock-drinking water guideline value.

Dissolved reactive phosphorus concentrations were typically above instream guideline values and were particularly high in the Irwell River, Hanmer Drain, Boggy Creek and Doyleston Drain (Figure 11). Nitrate/nitrite nitrogen concentrations were similarly high at most sites except for the Kaituna River (Figure 12). Suspended solids showed a wide range among sites (Figure 13). Dissolved nutrient concentrations

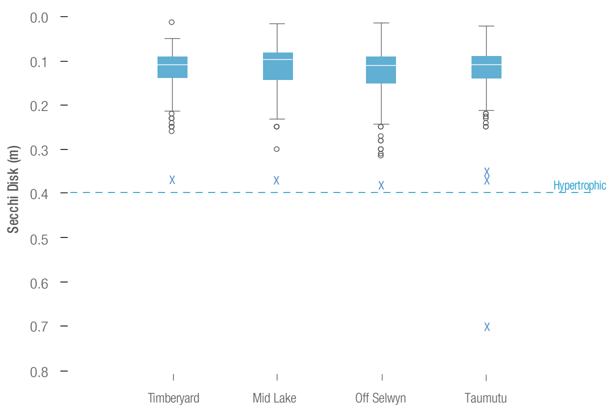

FIGURE 7. Secchi disk depth for four sites on Te Waihora/Lake Ellesmere (2002–2007). Note the reverse order of the y-axis.

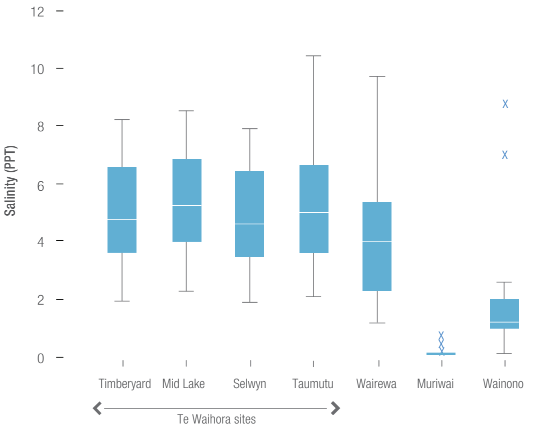

FIGURE 9. Salinity in four sites on Te Waihora/Lake Ellesmere compared to other coastal lakes (2002–2007).

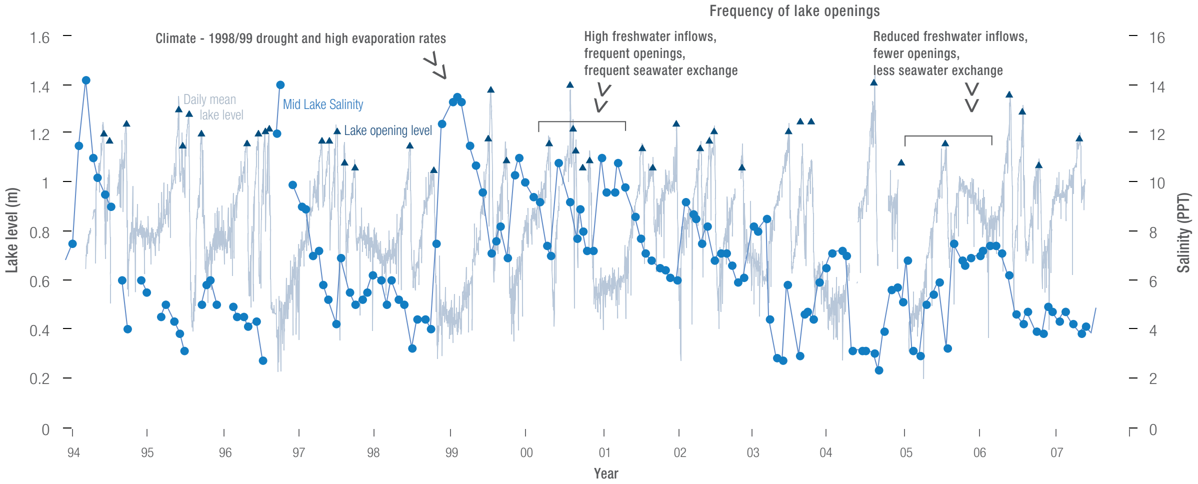

FIGURE 8. Drivers in change of salinity in Te Waihora/Lake Ellesmere (January 1994–2007).

exceeded guideline values in most streams, reflecting the vulnerability of these streams to adjacent land activities. In the case of nitrate/nitrite nitrogen, most is received via inflows of nitrate-enriched groundwater.

Different aspects of water quality are driven by different influences. Flows have a significant influence on water quality; many contaminants increase for short periods during floods. During periods of low flows, contaminants can also increase in concentrations because of lack of dilution and instream processes which release nutrients from sediments. Figure 14 illustrates this relationship in Boggy Creek, where dissolved phosphorus concentrations increase during low flow periods, particularly during the extreme low summer period of 2005-2006. During this period, dissolved oxygen decreased greatly, to well below recommended values (Figure 15).

In contrast to dissolved phosphorus, nitrate/nitrite concentrations were lowest during low flow periods (Figure 16). Furthermore, following the June 2006 snow event, nitrate/nitrite concentrations rose dramatically, exceeding the aquatic toxicity threshold. Boggy Creek is fed primarily by groundwater, which clearly has a strong influence on stream flows and nitrate concentrations.

Suspended solid concentrations have shown a considerable improvement over the past four years in Boggy Creek (Figure 17). This is not strongly related to flows, but reflects a significant improvement in riparian protection. Figure 18 shows mature vegetation that has been planted along Boggy Creek, which has resulted in reduced inputs of sediment.

Two aspects of flow have changed:

- Lower base flows of groundwater fed streams (all except Banks Peninsula streams) caused by climate (lack of winter recharge) as well as by increased groundwater abstraction
- Less frequent floods cause by climatic factors.

Invertebrate communities reflect water quality and habitat. Reduction in flows has had a major influence on the state of tributaries. For example, during the extreme low flow event of 2005/2006, the Selwyn River invertebrate community changed dramatically, with the loss of sensitive species (Figure 19).

Management issues

The loss of the macrophyte beds in the late 1960s resulted in a large increase in lake turbidity (especially at the lake margin) affecting people's perception of the lake as well as dramatically changing the primary production with cascading effects on other biota (e.g., trout, black swans). There have been frequent calls for efforts to restore the macrophyte beds. The feasibility of this is being investigated. If successful (as a long-term goal) this could have both positive and negative effects on the lake. Negative effects could include algal blooms around the lake margin because of clearer, calmer waters as well as problems with boat access.

Other perceptions of the health of the lake probably relate to recreational and fishing opportunities, and general appeal of, and access to, the lake margin rather that water quality *per se*.

The Canterbury region, as with many other regions, has undergone some major changes and intensification of agricultural

Photo **Visual water clarity of the lake is low and has declined at long term monitoring sites from 1998 through to 2007. However perceptions of health of the lake relate more to general appeal of the lake rather than just water quality issues.** Photography **Shelley McMurtrie.**

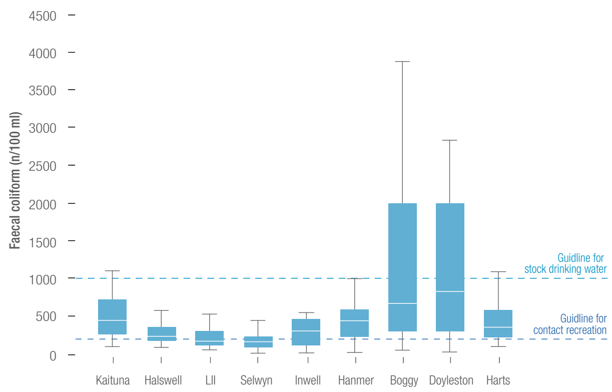

FIGURE 10. Faecal coliform concentrations in nine tributaries of Te Waihora/ Lake Ellesmere (2002–2007).

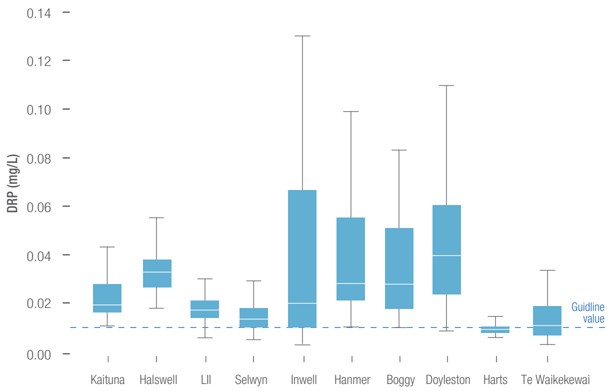

FIGURE 11. Dissolved reactive phosphorus (DRP) concentrations in ten tributaries of Te Waihora/Lake Ellesmere (2002–2007).

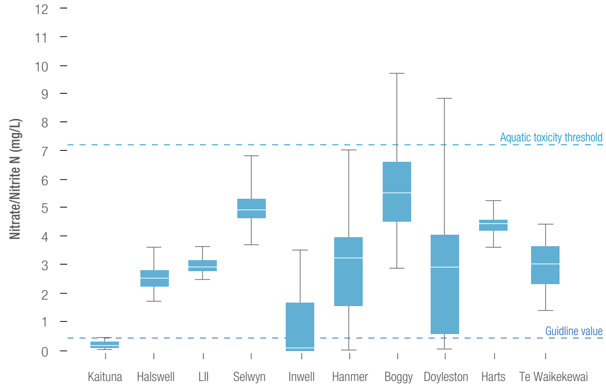

FIGURE 12. Nitrate/Nitrite Nitrogen concentrations in ten tributaries of Te Waihora/Lake Ellesmere (2002–2007).

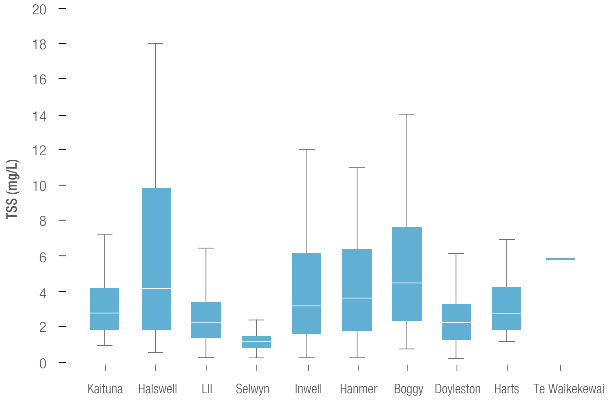

FIGURE 13. Total suspended solids (TSS) concentrations in ten tributaries of Te Waihora/Lake Ellesmere (2002–2007).

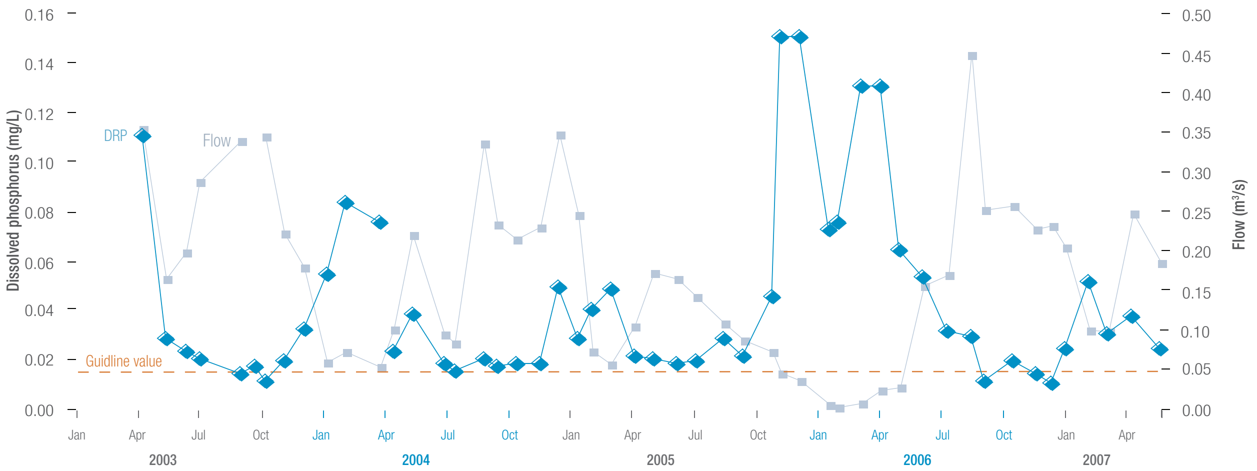

FIGURE 14. Dissolved reactive phosphorus (DRP) concentrations and gauged flows in Boggy Creek (2003–2007).

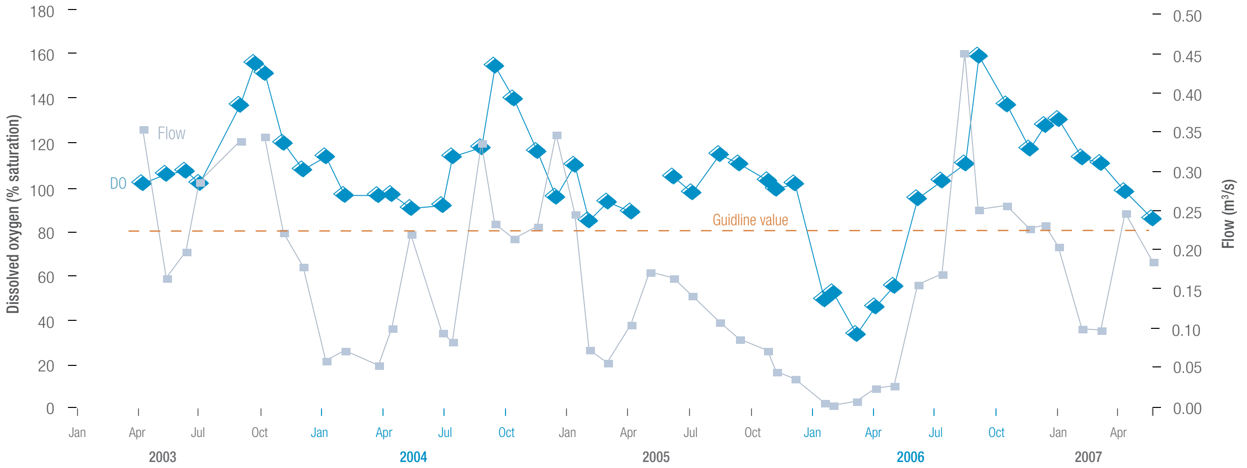

FIGURE 15. Dissolved oxygen (DO) saturation values and gauged flows in Boggy Creek (2003–2007).

FIGURE 18. Riparian planting and fencing along Boggy Creek.

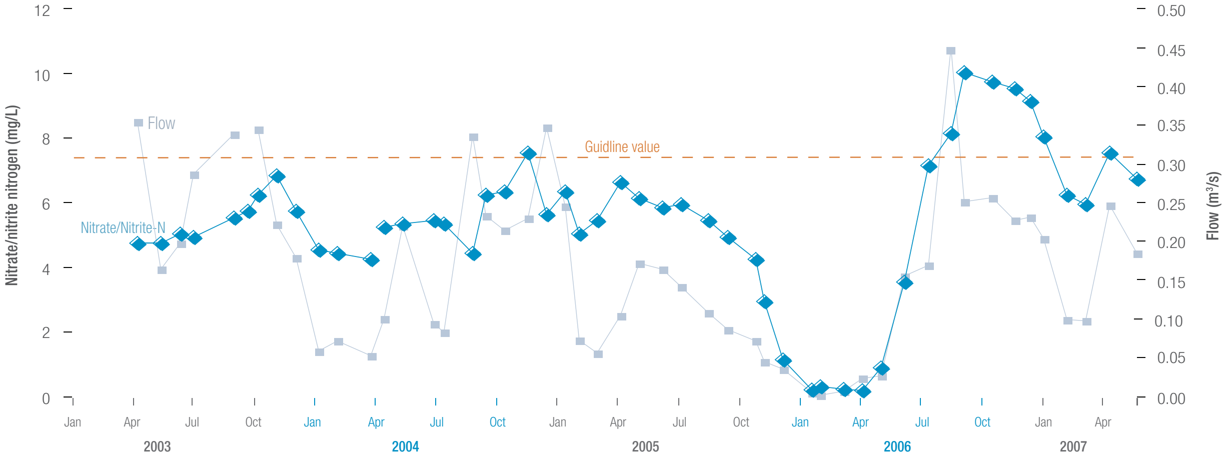

FIGURE 16. Nitrate/Nitrite Nitrogen concentrations and gauged flows in Boggy Creek (2003–2007).

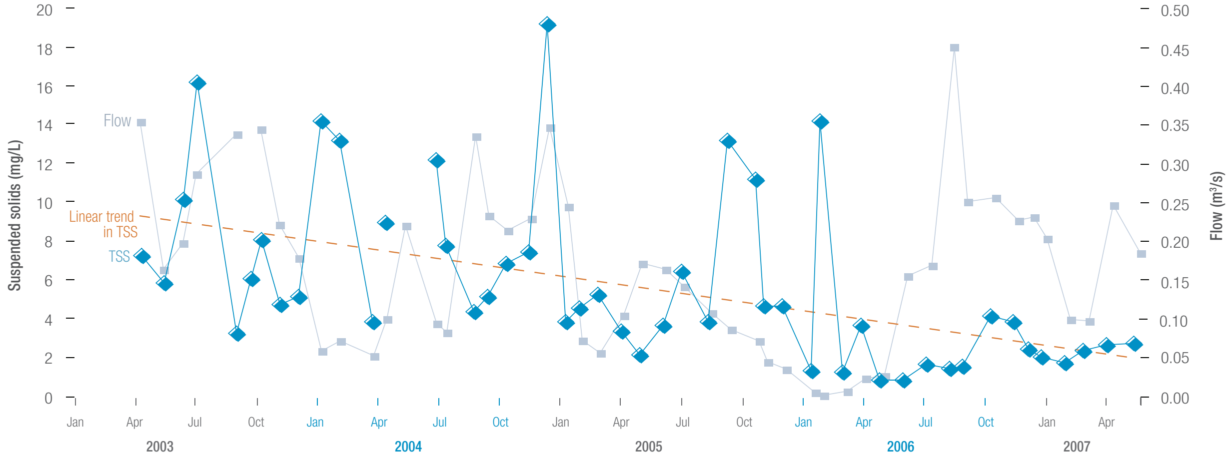

FIGURE 17. Total Suspended solids (TSS) concentrations and gauged flows in Boggy Creek (2003–2007).

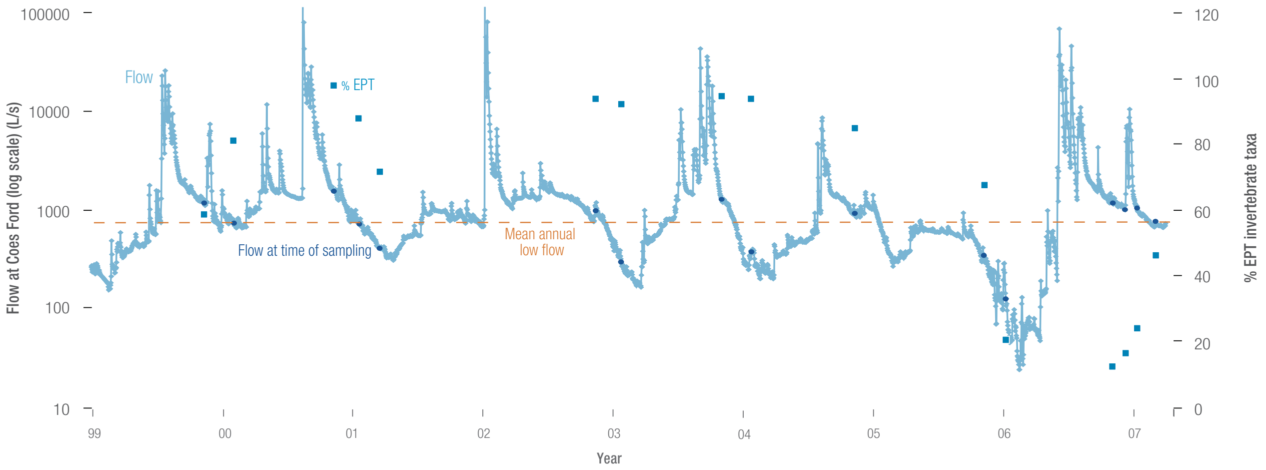

FIGURE 19. Invertebrate communities (%EPT) at Coes Ford, Selwyn River (January 1999–2007).

TABLE 3. **Lake water quality issues and management options.**

Issue	Management options and scale
Water clarity	Re-establish macrophyte beds?
Phytoplankton – high but not blooming (yet)	Reduce nutrient inputs? Currently limited by light availability
Salinity – habitat diversity	Changing with changing hydrology

TABLE 4. **Tributary issues and management options.**

Issue	Management options and scale
Reduction in flow	Catchment management / climate
High nitrate inputs	Catchment management of groundwater nitrates
High sediment, bacteria, phosphorus inputs	Adjacent land use-riparian zone protection

land uses. Figure 20 shows changes in fertiliser usage since 1992 and Figure 21 shows changes in stock numbers from 1996. It is unknown at this stage what amount of reduction in nutrient concentrations in the lake would result in a reduction in phytoplankton biomass. Therefore, there is still an information need to better understand to role of nutrients on phytoplankton growth rates and biomass.

However, it is reasonable to assume that reduction of nutrient inputs to the lake would be beneficial. A medium term goal could be complete riparian protection of all main tributaries, and requirement of farmers to undertake nutrient budgeting. A long-term goal may be to set nutrient allocation limits for the catchment, once we have a good understanding of what nutrient targets are needed for the lake and tributaries. Also, complete or near complete riparian protection of the lake margin (and bank stabilisation through sensible planting) could be long-term goal for both nutrient management as well as a range of other benefits to the lake and lake users.

We may not be able do much about the wind but a different lake level management may help reduce re-suspension of suspended solids. Improvements in riparian protection of streams and the lake margin to reduce erosion will help reduce sediment inputs to the lake.

Hydrological and salinity models are needed to enhance understanding the influence of lake openings, lake level management, relative importance of floods and base flow of tributaries, and other climatic factors such as the effect of temperature on evaporation rates (especially important for modelling climate change impacts).

Tables 3 and 4 summarise the range of management options to address the lake and tributary issues respectively.

3.5 Conclusions

Comparison of lake water quality pre-1990s appears to show that nutrient concentrations may have been higher in the lake in the 1970s and 1980s compared to the past 10 years. This is likely to be the result cessation or improvement of direct discharges of treated sewage (e.g. Lincoln township) and piggery and dairy shed effluent to waterways. Unfortunately there is inadequate chlorophyll a biomass data to look at whether phytoplankton biomass was previously higher or not.

Tributaries flowing into the lake have suffered from low flows over the past 10 years resulting in significant adverse effects on water quality and overall health of the aquatic ecosystems. Boggy Creek has recently exceeded the nitrate toxicity threshold for freshwater ecosystems. Land use intensification is likely to be one of the key drivers of these changes.

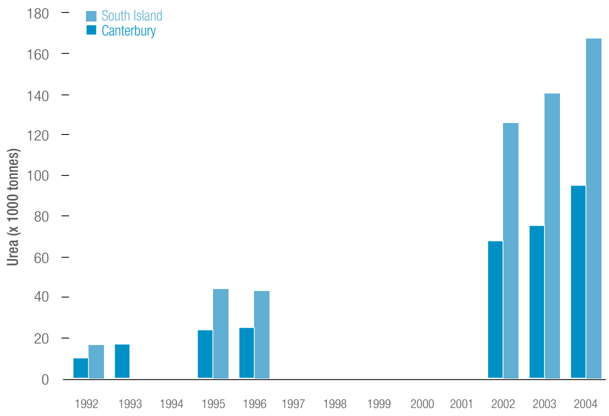

FIGURE 20. Drivers of change in fertiliser use in Canterbury and the South Island (1992–2004).

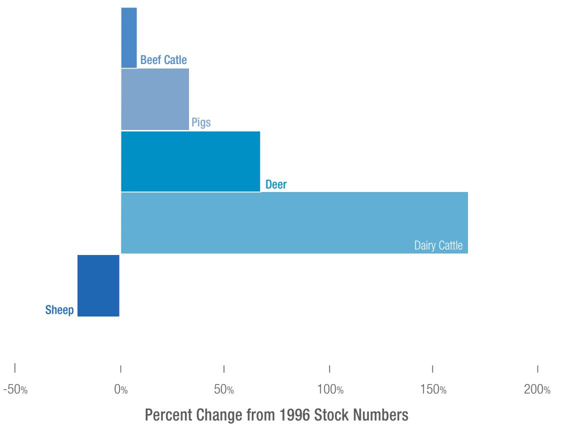

FIGURE 21. Changes in stock numbers in Canterbury (percent change from 1996).

Photo ***Despite some water quality issues, Te Waihora/Lake Ellesmere continues to support abundant and diverse wildlife and plant communities. Further benefits to water quality would require complete riparian protection in tributary waterways and the lakeshore, and reduction in nutrient losses from the catchment's agricultural areas.*** *Photography* ***Colin Hill.***

Further work on understanding the influence of water quality on the lake ecosystem as a whole is needed. Management intervention is required at a range of scales, ranging from land activities immediately adjacent to the lake and tributaries to catchment wide management of water quantity and quality (e.g., nitrates).

3.6 References

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SHELLEY McMURTRIE

04

VEGETATION of the lakeshore

PHILIP B. GROVE Environment Canterbury **MIRELLA POMPEI** Environment Canterbury

Te Waihora/Lake Ellesmere lakeshore vegetation was mapped and described in the early 1980s and again in 2007, allowing analysis of trends in vegetation cover around the lakeshore. Lakeshore vegetation types were categorised on the basis of habitat (brackish wetland/freshwater wetland/dryland) and canopy composition (native/exotic/mixed native-exotic). There has been an increase in total area of freshwater wetland habitats and a corresponding decline in overall cover of brackish wetland vegetation over the monitoring interval. Although the overall area of brackish wetland habitat has declined, there has actually been an increase in extent of native brackish wetland vegetation. And while there has been an increase in area of freshwater wetland habitat around the lakeshore, there has been a marked decline in extent of native freshwater wetland vegetation. Causes of these trends include the lower average lake levels and reduced lake salinity of recent years, reduced stock grazing pressure along parts of the shoreline, the spread of exotic willows in freshwater wetland habitats and human disturbance. Management actions to maintain, improve or restore the resource are suggested.

4.1 Introduction and methods

Te Waihora/Lake Ellesmere lakeshore vegetation was mapped and described in the early 1980s by Clark and Partridge (1984). The same area, approximately 4,400 ha in total, was re-surveyed in 2007. Information from both surveys has been entered into a spatial database allowing monitoring and analysis of trends in vegetation cover around the lakeshore.

A total of fifty-four vegetation types were identified and mapped by Clark and Partridge, and described in their survey report. Sixty-three vegetation types were described for the survey area in 2007. All vegetation types recorded in 1983 were present in the second survey, with nine new vegetation types identified and described.

An overview of the 2007 vegetation map is shown in Figure 1, with approximately 900 distinct mapping units delimited within the survey area. Where a mosaic of more than one vegetation type was present in a mapping unit, the types were listed in decreasing importance in terms of area. The full list of vegetation types present within each 'mosaic' mapping unit have been recorded on the spatial database. However, for purposes of trend analysis over the whole lakeshore survey area only the predominant vegetation type within each mosaic was used.

The area mapped in the 1984 report extended from the lake water's edge (at low lake level) to an upper boundary between the 1.0 and 2.0 metre contour. This upper boundary usually marked the change from lakeshore wetland vegetation to developed farmland or other dryland vegetation. While the focus of the survey, and majority of the survey area, was lakeshore wetland vegetation, some areas of farmland, raised stopbanks, sand dunes and other dryland vegetation types were also included in the vegetation maps (Clark and Partridge 1984).

In 2007, some additional sites of wetland vegetation outside the original survey area were mapped. These additional mapping units were not included in the spatial analysis of trends in the vegetation 1983-2007, and are not discussed further here. For some of the lowest-elevation

Photo ***A typical view of Te Waihora/Lake Ellesmere lakeshore vegetation illustrates the influence of fluctuating water levels and salinity on vegetation patterns. Much of the present nationally-significant lakeshore vegetation has developed under the artificial lake opening regime of the last 150 years.*** *Photography* ***Shelley McMurtrie.***

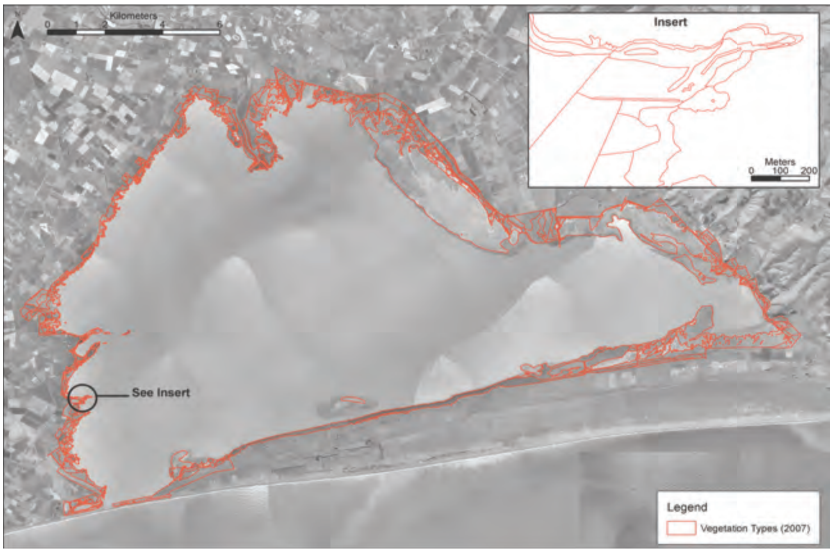

FIGURE 1. Vegetation mapping units for Te Waihora/Lake Ellesmere 2007.

FIGURE 2. Native brackish wetland vegetation: marsh ribbonwood shrubland (*Plagianthus divaricatus*) bachelor's button *(Cotula coronopifolia)* – purple mimulus (*Mimulus repens*) herbfield – Yarrs Flat.

FIGURE 3. Native brackish wetland vegetation: sea rush (*Juncus krausii*) and marsh ribbonwood at Kaitorete Spit.

FIGURE 4. Native brackish wetland at Greenpark Sands: Sea primrose (*Samolus repens*) hummocks amongst purple mimulus and arrow grass (*Triglochin striata*) on sparsely vegetated flats.

lakeshore vegetation types, mapping, and therefore total area calculations, were only approximate due to lake water levels at both survey times.

Lakeshore vegetation types were grouped into broader categories based on habitat:

- Vegetation of saltmarsh or brackish wetland habitats. These are extensive along the southern and eastern sides of the lake, but are also present on the western shoreline. Examples are shown in Figures 2-4.
- Freshwater wetland vegetation, generally around inflows and groundwater seepages and most abundant along the western side of the lake, e.g., Figures 5 and 6
- Higher-elevation dryland vegetation types.

Only native plant species occur on the lowest elevation lakeshore mud and sand flats. Most other wetland vegetation types contain both native and exotic species, but can be categorised as predominantly native, predominantly exotic or mixed native-exotic, on the basis of canopy composition. Dryland vegetation within the survey area is mostly exotic grassland and shrubland (gorse, lupin), except on Kaitorete Spit where some distinctive native dryland vegetation is also present. The minor 'miscellaneous' category includes unvegetated areas such as bare ground, stopbanks, tracks, ponds etc.

4.2 Current state of vegetation

There has been an increase in total area of freshwater wetland habitats and a corresponding decline in overall cover of brackish wetland vegetation over the monitoring interval of 1983-2007 (Table 1; Figures 7 and 8).

Brackish wetlands

Native vegetation types occupied 85% of brackish wetland habitats in 1983, the balance being exotic grassland. In 2007 native vegetation occupied over 90% of brackish wetland habitats. Although the overall area of brackish wetland habitat has declined, there has actually been an increase in total area of native brackish wetland vegetation over the monitoring interval. The main contributors to these trends were expansion in cover of marsh ribbonwood shrubland (256 to 387 ha) and three square *(Schoenoplectus pungens)* sedgeland (123 to 401 ha); and a decline in cover of exotic salt-tolerant grassland (tall fescue, creeping bent, salt barley grass) from 536 to 331 ha.

Freshwater wetlands

While there has been an increase in cover of freshwater wetland habitat around the lakeshore, there has been a marked decline in extent of native freshwater wetland vegetation. In 1983 native freshwater wetland vegetation covered 245 ha, 54% of the available habitat (452 ha). By 2007, native freshwater wetland vegetation cover was reduced to 197 ha, only 35% of a larger total area (555 ha). For example, area of native harakeke / NZ flax *(Phormium tenax)* cover declined from 23 to 9 ha. Area of exotic crack- and/or grey willow- *(Salix fragilis and S. cinerea)* dominant forest and scrub vegetation has doubled, from 67 ha of the lakeshore survey area in 1983 to 140 ha in 2007.

Botanically important areas

Clark and Partridge (1984) listed several lakeshore areas as having high botanical value. Greenpark Sands, Kaitorete Spit, the west bank of the LII River and Yarrs Flat Wildlife Reserve retain the values that caused them to be identified as botanically important wetland areas almost 25 years ago. Together, these areas comprise approximately one third of the lakeshore.

However, the smaller botanically important wetlands described by Clark and Partridge on the lake's western shore, areas north of Lake Road South, the point south of Timber Yard Point, and Harts Creek Wildlife Management Area, have been reduced. Despite being only a small, and decreasing, proportion of the total area, the remaining native freshwater wetlands are

FIGURE 5. A distinctive native freshwater vegetation type: *Baumea rubiginosa* restiad rushland with scattered flax and manuka (*Leptospermum scoparium*), at Lakeside Reserve on the western shoreline.

FIGURE 6. Grey willow invading tussock sedge (*Carex secta*) swamp near the mouth of the LII River.

TABLE 1. **Changes in proportion of vegetation types between 1983–2007.**

Habitat	Proportion of lakeshore survey area	
	1983	2007
Brackish wetland	82% (3,606 ha)	80% (3,534 ha)
Freshwater wetland	10% (452 ha)	12% (555 ha)
Dryland	8% (332 ha)	8% (337 ha)
Miscellaneous	< 1% (11 ha)	<1% (13 ha)
Total	4401 ha	4439 ha

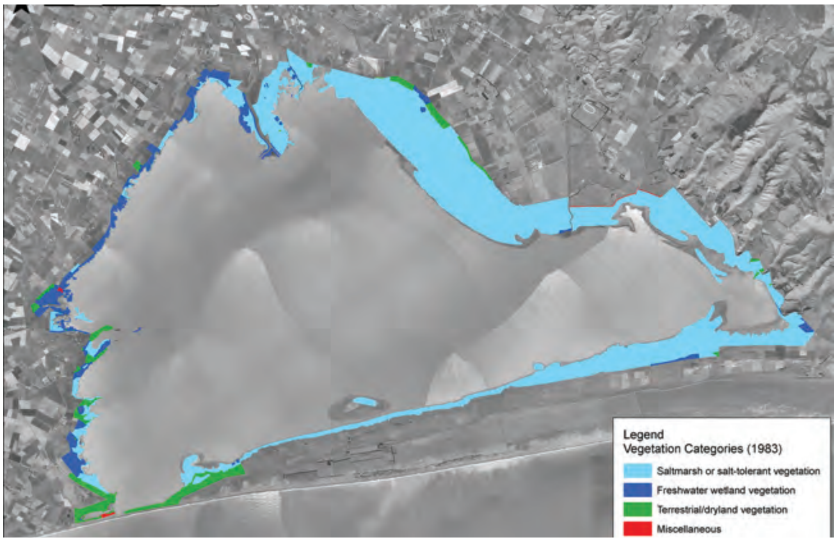

FIGURE 7. Patterns of lakeshore vegetation – 1983.

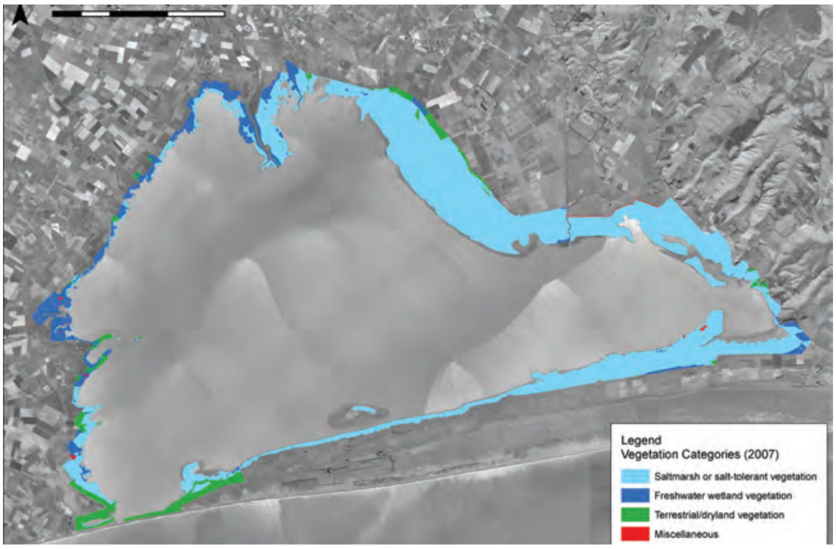

FIGURE 8. Patterns of lakeshore vegetation – 2007.

FIGURE 9 An example of the effect of even small differences in elevation on the distribution of lakeshore saltmarsh vegetation.

an important component of the lakeshore environment. They include significant examples of regionally uncommon and distinctive vegetation types, e.g., Figure 5, and are critical habitat for a number of rare/threatened plant and bird species.

4.3 What has caused the state and recent trends

Clark and Partridge (1984) attributed variation in the lakeshore vegetation to three main factors: elevation in relation to lake level; degree of salinity; and the effects of human disturbance (Taylor, 1996). Human disturbance includes direct clearance of vegetation, construction of drains and stopbanks and the spread of introduced plants and animals. These factors continue to drive lakeshore vegetation patterns. Other factors are substrate physical composition (sand, silt, gravel) and nutrient concentrations.

Present lakeshore vegetation has developed under the artificial lake opening regime of the last 150 or so years. Vegetation zonation patterns along the lakeshore reflect the varying tolerance to inundation and exposure of different plant species (Figure 9). There is also a gradient from freshwater to brackish to saline conditions at different times and places around the lakeshore, influenced both by water salinity and substrate type (sandy soils are more saline than silt/mud).

Freshwater wetlands occur in the vicinity of surface and groundwater inflows. Brackish wetlands, supporting species tolerant of fluctuating salinity, occupy most of the lakeshore. The most saline conditions around the lakeshore are on mid-elevation sand flats, where brackish lake water forms shallow ponds during high lake levels, and salts are concentrated by subsequent evaporation. Only a few of the most salt-tolerant plant species can grow here: native glasswort *(Sarcocornia quinqueflora)* and salt grass *(Puccinellia stricta)*, and introduced salt barley grass *(Hordeum marinum)*. Figure 10 in shows an example of this vegetation.

4.4 Recent trends

The overall decrease in brackish wetland and increase in freshwater wetland area of the last 25 years is probably a response to the lower average lake levels and reduced lake water salinity (due to fewer lake openings) of recent years. In spite of this, cover of native brackish wetland vegetation, specifically marsh ribbonwood and three square, has increased over the same time, owing to reduced pressure from stock grazing along parts of the lakeshore. Figure 11 in illustrates the effect of cattle grazing on three square at a site on Kaitorete Spit.

Spread of willows and conversion of some areas to pasture are the main causes of increased extent of exotic freshwater wetland vegetation types, at the expense of native plant communities in these habitats (Figure 6). However, there has been an increase in abundance of some native species (e.g., bog rush *Schoenus pauciflorus* and *Carex sinclairii)* within mixed native-exotic freshwater wetland vegetation types at several sites on the western shoreline, in response to reduced grazing pressure. These may revert to native dominance in the future.

The botanically important freshwater wetlands described by Clark and Partridge (1984) on the lake's western shore continue to be reduced by both weed spread and human disturbance (including clearance for farming, herbicide and fire). A recent example was the spraying (2006-07) and subsequent burning (May 2007) of native freshwater wetland at Lakeside Scientific Reserve. The only remaining stand of manuka on the Te Waihora/Lake Ellesmere shoreline was destroyed, along with several hectares of *Baumea rubiginosa*, flax and raupo swamp.

FIGURE 10. Hyper-saline native herbfield vegetation. Halophytic glasswort and saltgrass at Greenpark.

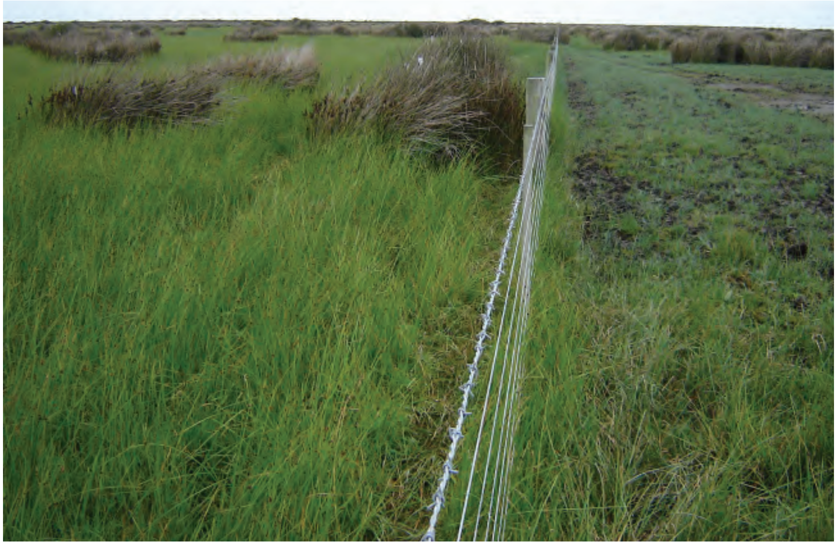

FIGURE 11. A fenceline at Kaitorete Spit illustrates effects of grazing on three square sedgeland.

4.5 Actions required to maintain, improve or restore the resource

Maintain

- No further loss of native lakeshore wetland vegetation by human disturbance (e.g. clearance for farming, heavy stocking, herbicide, fire, earthworks, vehicles).
- No further disturbance to lakeshore hydrology through construction of drains and stopbanks.
- Prevent spread of willows and other weeds into non-infested areas. Eradicate willows and shrub weeds from lightly-infested sites in ways that do not harm existing native plants.
- Implement the Water Conservation Order lake closing regime, particularly in the event of summer openings. If the lake level gets very low in summer, it can take a long time to refill. Wetland plant communities dry out and are invaded by exotic dryland species.
- Maintain lake level fluctuations with the opening and closing regime but with higher maximum lake opening trigger levels (e.g. 1.3 m). This would help compensate for lower lake levels of recent years. A higher lake level will also help restrict willow spread.

Improve

- Eradicate willows and other weeds from moderately-infested sites in ways that do not harm existing native vegetation.
- Fence lakeshore wetlands from adjoining developed farmland to control or exclude stock grazing.

Restore

More ambitious actions, and on a wider catchment scale, would be required to achieve restoration of native lakeshore vegetation. These might include:

- Fill in drains and remove stopbanks around the lake to restore hydrological connectivity and raise water table.
- Restore quantity and quality of freshwater inflows.
- Restore native vegetation connections over the catchment; to Banks Peninsula and across the plains to the mountains.
- Eradicate willows from heavily infested sites and actively replant with appropriate native species.

4.6 Acknowledgements

Thanks to Alice Shanks for field survey and mapping of the western lakeshore, and Trevor Partridge (Christchurch City Council) for useful discussion.

4.7 References

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Taylor, K.J.W. (ed.) 1996. The Natural Resources of Lake Ellesmere (Te Waihora) and its Catchment. Canterbury Regional Council Report 96(7), Canterbury Regional Council, Christchurch.

Photo *One of the primary actions required to maintain, improve, and restore the natural lakeshore vegetation is the control of willows.*
Photography **Shelley McMurtrie.**

GREG KELLY

05

NATIVE FISH and fisheries

DONALD J. JELLYMAN NIWA **CLEM G. SMITH** Taumutu

Te Waihora/Lake Ellesmere supports diverse and substantial fish stocks. In addition to important commercial fisheries, the lake supports very important customary fishery values. Key species are shortfin eels, flounders (black, sand, and yellowbelly), and yelloweye mullet. The trends in these fisheries are reviewed, and the importance of spring lake opening is emphasised. Management indicators and goals are presented.

5.1 Introduction

Te Waihora/Lake Ellesmere is a large (20 000 ha) shallow coastal lake in Canterbury formed by the longshore drift of gravel that has created a barrier bar (Kaiterete Spit). The lake has a maximum depth of 2.5 m (Irwin et al. 1989), is highly turbid (Secchi depths < 0.2 m; Glova and Sagar 2000), and salinity normally ranges between 5-10 ppt (Lineham 1983; Gerbeaux 1989). The lake is a taonga to Ngāi Tahu and provides a major source of mahinga kai and mana (Te Rūnanga o Ngāi Tahu and Department of Conservation 2005). As part of the Ngāi Tahu Claims Settlement Act 1998, the Crown vested the bed with Ngāi Tahu. The Department of Conservation (DoC) administers significant other lands adjoining the margins of the lake, and with Ngāi Tahu developed a Joint Management Plan (Te Rūnanga o Ngāi Tahu and Department of Conservation 2005) that outlined policies to maintain or enhance the significant values of the lake.

In recognition of its outstanding value as a wildlife (waterfowl) habitat, a National Water Conservation Order was granted in 1990. This order provides for the present summer and winter opening trigger levels, (1.05 and 1.13 m asl respectively), but has provision for an additional opening during 15 September–15 October pending the granting of resource consents to an interested party.

The lake maintains important customary and commercial fisheries, as well as providing a conduit for recruitment of diadromous fish to the Selwyn and other tributaries. A wide range of fish species has been encountered within the lake or Selwyn catchment (Table 1), including a group of marine species that opportunistically enter the lake during prolonged openings. Species lists have been compiled by Ryan (1974), Hardy (1989), and Taylor (1996). Important mahinga kai and commercial species are flounders (3 main species–black, sand, and yellowbelly), shortfin eels, and yelloweye mullet. A recreational whitebait fishery exists at the mouth of the lake and in several tributaries when there is a spring opening.

TABLE 1. **Fish species recorded from Te Waihora/Lake Ellesmere, and the Selwyn catchment.**

Common name	Scientific name	Te Waihora	Selwyn catchment
Freshwater/estuarine species			
Yelloweye mullet	*Aldrichetta forsteri*	***	*
Shortfin eel	*Anguilla australis*	***	***
Longfin eel	*Anguilla dieffenbachii*	**	**
Goldfish	*Carassius auratus*	**	*
Torrentfish	*Cheimarrichthys fosteri*	*	*
Giant kokopu	*Galaxias argenteus*	?	
Koaro	*Galaxias brevipinnis*	*	
Banded kokopu	*Galaxias fasciatus*	*	
Inanga	*Galaxias maculatus*	**	*
Canterbury galaxias	*Galaxias vulgaris*		**
Lamprey	*Geotria australis*	*	*
Upland bully	*Gobiomorphus breviceps*		***
Common bully	*Gobiomorphus cotidianus*	***	**
Giant bully	*Gobiomorphus gobioides*	*	*
Estuarine triplefin	*Grahamina* sp.	*	
Canterbury mudfish	*Neochanna burrowsius*		*
Common smelt	*Retropinna retropinna*	**	*
Stokells smelt	*Stokellia anisodon*	*	
Black flounder	*Rhombosolea retiaria*	***	
Koura	*Paranephrops* spp.		*
Perch	*Perca fluviatilis*	*	*
Brook char	*Salvelinus fontinalis*		*
Brown trout	*Salmo trutta*	*	**
Rudd	*Scardinius erythrophthalmus*	*	
Catfish	*Ameiurus nebulosus*	?	
Tench	*Tinca tinca*	*	
Chinook salmon	*Oncorhynchus tshawytscha*	*	
Marine species			
Kahawai	*Arripis trutta*	*	
Yellowbelly flounder	*Rhombosolea leporina*	***	
Sand flounder	*Rhombosolea plebeia*	***	
Greenback flounder	*Rhombosolea tapirina*	*	
Common sole	*Peltorhamphus novaezelandiae*	*	
Sprat	*Sprattus antipodum*	*	
Hake	*Merluccius australis*	*	
Sand stargazer	*Crapatalus novaezelandiae*	*	
Estuarine stargazer	*Leptoscopus macropygus*	*	
Sand eel	*Gonorynchus gonorynchus*	*	
Red cod	*Pseudophycis bachus*	*	
Basking shark	*Cetorhinus maximus*	*	
Rig	*Mustelus antarcticus*	*	
Elephant fish	*Callorhynchus milli*	*	
Spiny dogfish	*Squalus acanthias*	*	
Skate	*Raja nasuta*	*	
Globefish	*Contusus richei*	*	
Spotty	*Pseudolabrus celidotus*	*	
Warehou	*Seriolella brama*	*	
Red gurnard	*Chelidonichthys kumu*	*	

?	**status uncertain**
*	**recorded**
**	**often found**
***	**common**

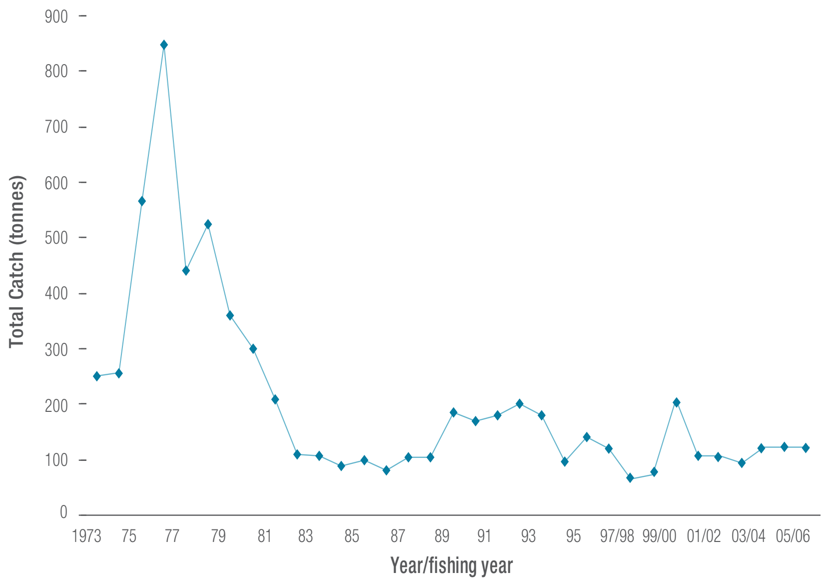

FIGURE 1. Trends in commercial catch of eels from Te Waihora/Lake Ellesmere.

5.2 Data sources

Data from the commercial fisheries were obtained from the Ministry of Fisheries. Te Waihora/Lake Ellesmere comprises one of the six South Island Eel Return Areas. However, for flatfish and mullet, Te Waihora/Lake Ellesmere is part of a wider return area, comprising a significant part of the east coast of the South Island. Further, flatfish recorded by Licenced Fish Receivers (LFR's) are recorded under a generic "flatfish" code. To obtain data on species proportions, we accessed the Catch Effort Landing Return database (compiled from individual fishers' catch estimates) where species are recorded. Any "unidentified flatfish" were allocated to species on a pro-rata basis according to the portion of the catch where species were identified.

The size and age composition of the commercial eel fishery has been part of the Ministry of Fisheries periodic catch-monitoring programme (Beentjes 1999; Beentjes and Chisnall 1997, 1998). Likewise, trends in the catch-per-unit-effort (CPUE) have been analysed (Jellyman 1993; Beentjes and Bull 2002), and the status of the fishery assessed (Jellyman et al. 1995, 2003a). Data on customary harvest from the lake are compiled by Ngāi Tahu from permits issued by lake kaitiaki.

5.3 Commercial eel fishery

Development of the fishery

The eel fishery commenced in the early 1970s and rapidly rose to be the largest single fishery in 1976 (Figure 1), when it comprised almost half of the total New Zealand eel catch. Because of concerns over declining catches, the lake was declared a controlled fishery in December 1978, with the initial Total Allowable Catch (TAC) set at 256 t (which did not include migratory eels) and allocated to 17 fishers. The TAC was reduced to 136.5 t in 1986 and distributed among 11 fishers. Although the lake had an initial size limit of 150 g (1994), this was progressively increased at 10 g/year to reach the national minimum size of 220 g.

A concession area and period was introduced at Taumutu in 1996, whereby fishers could target migrating shortfin males that were less than the legal minimum size. This regulation continues and the migrant eel fishery is generally targeted at 90-100 t per year. This is the only targeted fishery for migrating eels in New Zealand (migrating eels are normally released by fishers as a conservation measure), and capture of these males eels reduces the pressure on the remainder of the TACC (Total Allowable Commercial Catch), which is a fishery for non-migratory (feeding) shortfin females (as males do not exceed 220 g).

The merits of targeting male eels has been advocated by Jellyman and Todd (1998) as a means of conserving females, and utilising the extensive common bully population of the lake which form the major prey of larger eels (Kelly and Jellyman 2007). With the entry of South Island eels into the Quota Management System (QMS) in 2000, the TAC was reviewed and allocations made for customary and recreational use (customary = 31.26 t, recreational = 3.13 t). There are presently five commercial eel fishers on the lake, and the TACC (121.93 t) is almost invariably caught.

Changes in species composition, sizes, and growth rates of eels

Unfortunately, there are few historic data on species composition. In common with other lowland lakes, shortfin eels were always the dominant species in Te Waihora/Lake Ellesmere (Trevor Gould, former commercial fisher and processor, pers. comm.). As longfins prefer flowing water (Jellyman et al. 2003b), there will always have been substantial numbers of longfins in the lower reaches of tributaries and associated lake margins. During initial research surveys (NIWA unpubl. data), a higher proportion of longfins was recorded than in subsequent years, i.e., 1974-82, N = 6961, longfins = 4.3%; 1997-98, N = 1242, longfins = 0.5% (Beentjes 1999).

This reduction will be largely associated with onset of commercial fishing (longfins are more vulnerable to fyke net capture than shortfins; Jellyman et al. 1995; Jellyman and Graynoth 2005), but possibly also associated with the loss of aquatic macrophytes that resulted from the Wahine Storm in 1968. Some longfins are still present in the lower reaches of tributaries and nearby lake margins, as indicated by sampling in early 2007 where no longfins were caught at Timberyard Point (n = 152) but 11 % of eels from the Harts Creek Reserve were longfins (n = 313).

Fishery independent surveys have been used over a number of years, to monitor trends in the sizes of eels, and their growth rates. Eels are aged from their otoliths (earbones), and the average annual growth increment is calculated as:

increment = (length - 60mm)/age

where 60 mm represents the average length of glass eels.

The onset of commercial fishing has the potential to rapidly alter the size structure of eel populations, as evidenced by the changes in the length-frequency of eels sampled from Kaituna Lagoon in 1974 (commercial harvest just commencing in this area) and 1977 when fishing had been underway for 3 years (Figure 2). However, samples from Timberyard Point (Table 2) show virtually no changes in average sizes of shortfins over time. Migrating males have shown a marked decline in average size over time, although this decline has been arrested in recent years (Figure 3).

Although there has been little change in the average size of shortfins, there has been a marked increase in growth rates (Table 3); thus in 1974, shortfins (feeding eels) averaged 24 mm /year, but by 2007, the rate had increased by 63 % to 39 mm/year. The growth rate of migrating males does not appear to have changed much over the years (Table 3), but the growth rate and average size (Table 3, Figure 3) of (migratory) females have both increased substantially between the 1970s and 1998. Presumably, conditions for growth of larger eels have improved over time, possibly as a result of a reduction in overall numbers.

Female eels show accelerated growth rates with increasing size, associated with their change in diet from invertebrates (Kelly and Jellyman 2007) to fish (Jellyman 2001). However, the growth rate of juvenile eels is slow (Graynoth and Jellyman 2002) and this shows in the smaller annual growth increment for migrating males relative to females (Table 3) as males are too small to eat fish.

Movements of feeding eels

Recaptures of tagged eels have shown that most eels do not move extensively within the lake-a total of 1982 of 9956 tagged eels were recaptured over a period of five years, and most were caught at, or adjacent to, their original site (Jellyman et al. 1996). Transplanted eels showed a tendency to home to their original capture site. Likewise, eels sampled in 2007 from within the Hart's Creek Wildlife Management Reserve, were significantly larger than eels from Timberyard Point ($p < 0.05$), a distance of only 3 km, again indicating limited movement between the areas.

Catch rates of eels

Catch-per-unit-effort (CPUE, measured as kg of eels/net/night) analyses of Te Waihora/Lake Ellesmere commercial catches have not shown significant changes over the 9 years for which consistent data are available (Beentjes and Bull 2002). Similarly, when catches are adjusted for the influence of climate, season, and fisher (standardised CPUE), there was still no significant change. As fishers use larger nets than elsewhere in the country, the CPUE between 1990-91, and 1998-99 ranged between 113 and 247 kg/net/day.

TABLE 2. **Mean length (mm) and weight (g) of feeding eels from Timberyard Point, for various years.**

Species	Year	Number	Length		Weight	
			Mean	SE	Mean	SE
Shortfin	1974	230	466	6.2	234	9.7
	1975	1208	456	2.6	209	4.1
	1994	265	437	6.3	208	13.8
	2007	150	469	7.7		
Longfin	1974	215	392	4.4	164	11.9
	1975	81	415	9.4	182	35.7
	1994	8	543	55.2	483	203.9

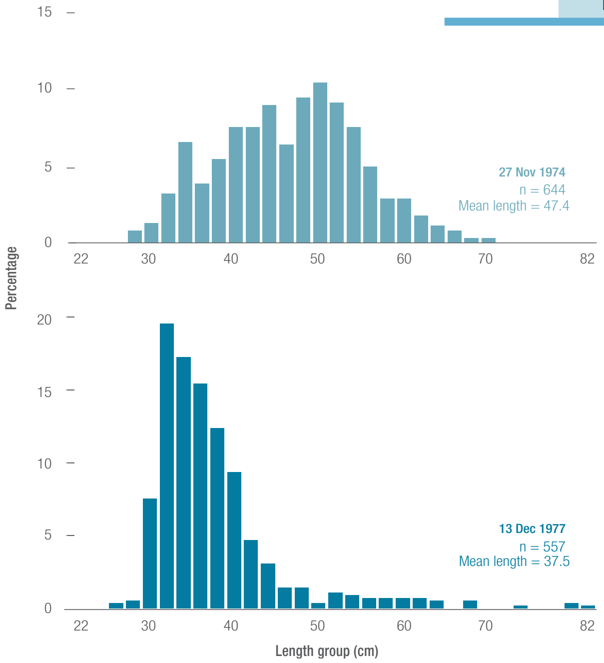

FIGURE 2. Kaituna Lagoon – length-frequency of two samples of shortfin eels collected three years apart.

TABLE 3. **Mean annual growth increment (mm/year) for feeding eels from Timberyard Point, and migrating eels from Taumutu, for various years.**

Species	Status	Year	Number aged	Mean increment (mm/year)	SE
Shortfin	Feeding	1974	230	24.0	0.3
		1975	1208	25.6	0.2
		1994	265	31.2	0.6
		1996/97*	116	35.3	0.5
		2007	65	38.9	1.0
	Migrant males	1975-82	2389	25.1	0.1
		2006	39	26.4	0.6
	Migrant females	1972-80	181	25.8	
		1998	50	47.3	
Longfin	Feeding	1974	215	24.9	0.4
		1975	81	25.3	0.6
		1994	8	32.4	4.2
		2007**	13	25.2	2.3

* Beentjes and Chisnall 1998

** sample from Harts Creek reserve.

5.4 Commercial flatfish fishery

Trends in the fishery

The flounder fishery has a history of extreme variability (Figure 4), with catches in adjacent years varying up to 10 fold. While this variability is thought to be largely due to the timing and duration of lake openings (Jellyman 1992; Taylor 1996), it also reflects the variability of recruitment of juvenile flatfish generally (Annala and Sullivan 1997). In 1959, there were 39 vessels and 55 fishers engaged in flounder fishing on the lake. Flounders were declared a quota species in 1986, and currently only eight fishers engage in commercial fishing.

Species composition

The catch is dominated by three main species - black flounder, yellowbelly flounder, and sand flounder. Occasionally small quantities of greenback flounder are recorded. Although juvenile common sole frequently enter the lake, they do not survive to enter the fishery. The species proportions vary considerably from year to year (Figure 5), but blacks provide the bulk of the catch (58% over past 23 years), followed by sands (22%) and yellowbellies (20%). While these are the proportions derived from fishers estimates, we are surprised at the putative high proportion of sand flounders, as our experience indicates sand flounders have normally been a relatively minor component of the catch (e.g. < 5%); we suspect coding errors have led to an over-representation of sand flounders.

Relationships with lake opening

Although Taylor (1996) reported a significant relationship ($R^2 = 0.39$, $p < 0.005$) between annual flatfish catches and the duration of lake openings (August-November) 3 years previously, we found no such predictive relationships, despite having a larger database, and investigating a variety of lags. The best relationship we found was for the % of days open between August and November, lagged by 2 years ($R^2 = 0.042$, $p > 0.05$). Seemingly, the relationship between lake openings and flounder abundance is not a simple cause-and-effect one, but will also reflect the national situation where strong year classes of flatfish are common. For example, for the past 16 years, there was a significant correlation between lake catches of yellowbelly flounders and catches for the rest of New Zealand ($p = 0.05$), although the same relationship for sand flounders was not significant ($p = 0.42$). As the lake produces over 2/3 of the total New Zealand catch of black flounders, this relationship was highly correlated ($p < 0.000$).

As the fishery is based on 2- and 3-year old fish (Gorman 1960), loss of a year's recruitment will have a profound effect, unlike eels where fish are typically > 10 years at entry into the commercial fishery.

Movements

Apart from the spring recruitment of juveniles, mature adults emigrate from the lake to spawn at sea. The spawning season in flounders can be prolonged, from August-November (Colman 1973). In Te Waihora/ Lake Ellesmere, maturing flounders migrate from the lake during any opening in winter; yellowbellies and sands often have pronounced ovaries throughout long periods of the year, indicating extensive breed-

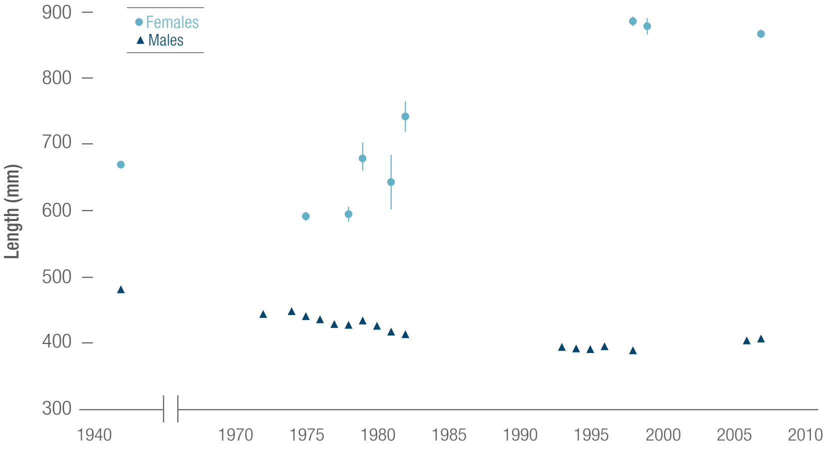

FIGURE 3. Changes in the average length of migratory male and female shortfin eels (bars = SE).

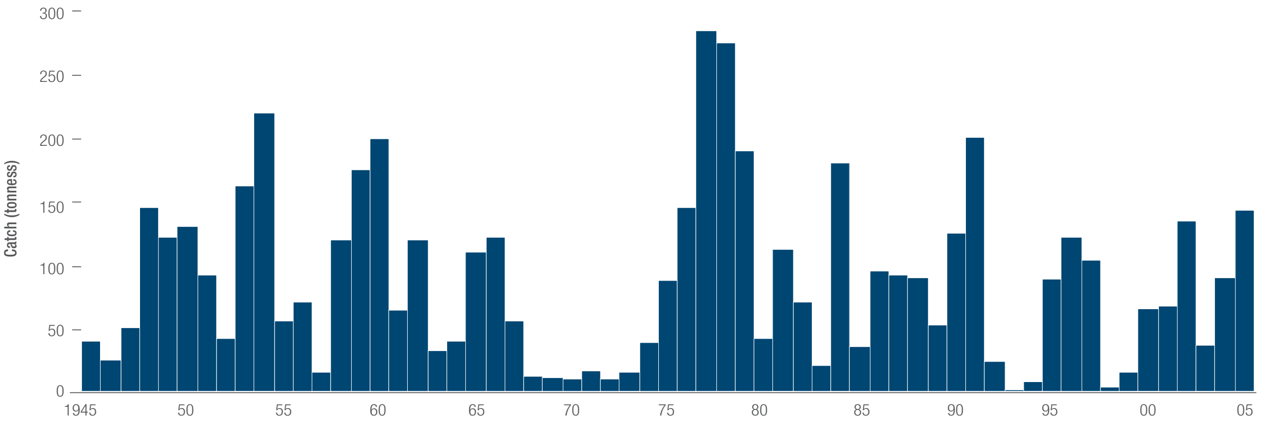

FIGURE 4. Te Waihora/Lake Ellesmere: commercial flounder catches, 1945-2005.

ing seasons, while blacks appear to mature more rapidly, with nearly mature fish congregating at Taumutu in July and August. As flounders are essentially shallow-water species, spawning grounds will be inshore (Paul 2000).

Movements of tagged flounders within the lake showed no obvious pattern (Gorman 1960), with some moving from Taumutu to Halswell within 10 days, while others showed no overall movement three weeks after liberation. Six were recaptured at sea, of which one black flounder was caught off Nugget Point, Otago, a distance of 320 km achieved in 175 days.

5.5 Commercial yelloweye mullet fishery

The mullet fishery is also rather variable, with fluctuations reflecting both recruitment from the sea, and also market demands. Over the past 18 years, the annual catch has averaged 6.4 t (SE 1.4 t), with a maximum of 22.8 t in 1992. The fishery is essentially a winter one, with an average of 2/3 of the catch taken between June and August inclusive and 92% between May and September.

5.6 Customary fisheries

A review of the historic and present-day importance of Te Waihora/Lake Ellesmere to Ngāi Tahu is outside the scope of this paper. The extent of customary harvest over the past 4 seasons (Table 4) indicates up to 5 t of patiki (flounder) and tuna (eels) have been harvested per year. For eels, these figures are well within the 31.26 t allocated for customary harvest by the TAC process. Such levels of harvest are obviously well below historic levels.

5.7 Discussion

Fish behaviour

Wind has a major influence on lake ecology, by resuspending sediment and reducing water clarity (and thus limiting opportunities for macrophyte re-establishment (Sagar et al. 2004), but also by influencing movements of fish. Eels, flounders, and mullet all move with the wind, possibly taking advantage of wind-derived currents. Feeding shortfin eels are inactive at water temperature < 12 °C, but once temperatures exceed this, they commence feeding and moving, especially in spring and early summer. Although the activity of feeding eels can be adversely affected by bright moonlight, migrating eels are more sensitive to moonlight and also to wind, and a northeast wind will move them to Taumutu in large quantities. Should a strong southerly produce waves that overtop the spit, then eels become very active and may even wriggle across the bar to reach the sea.

Flounders move with the wind at all stages of their lifecycle. The most obvious movements are the arrival of mature black flounders at Taumutu in July and August during northeast winds, whereas they move away during a southerly. Mullet move with the wind in summer, but imto the wind in winter-they are also affected by cold weather and frosts result in them forming schools.

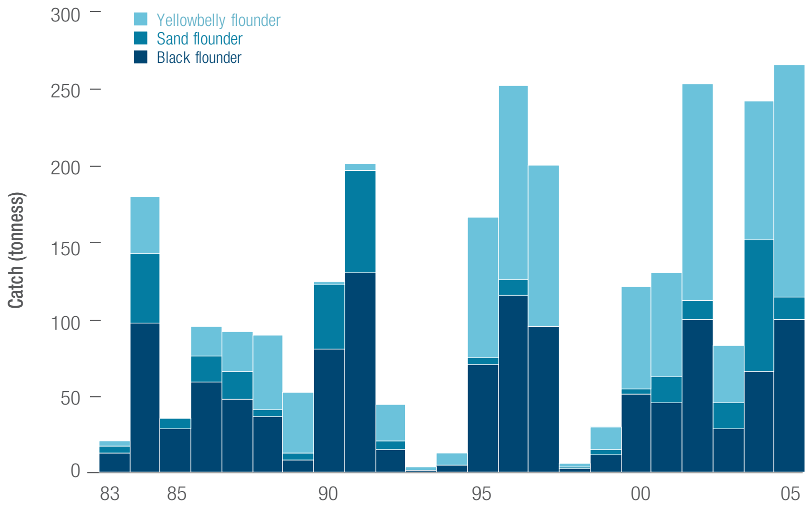

FIGURE 5. Te Waihora/Lake Ellesmere flounder catches – species proportions, 1983–2006.

TABLE 4. **Approximate customary harvest (data supplied by Ngāi Tahu). Weights of fish assume average weights of 450g and 1 kg for flounders and eels respectively.**

Year	Patiki (Flounders)		Tuna (eels)	
	Number	Approx weight (kg)	Number	Approx weight (kg)
2003	1200	540	1400	1400
2004	2200	990	800	800
2005	11400	5130	4700	4700
2006	2700	1215	1700	1700

Overall status of exploited fish stocks

Eels

The extent of commercial harvest is set by the TACC process, and is subject to annual review by the Ministry of Fisheries. Historical yields from the lake were excessive, but the present TACC appears sustainable, although this could be jeopardised by inadequate recruitment. Emphasis on capture of migrating male eels is an important measure to reduce the harvest of females.

The Te Waihora Management Board (representing customary fishers) remain concerned about an overall reduction in eels of sufficient size (e.g. > 0.5 kg), and their access to such eels. Because there is arguably a lower biomass of eels of both species than was present at the onset of commercial fishing, the condition of eels has improved markedly over time; whereas previous researchers (Hobbs 1947) mentioned the presence of "stockwhip" eels (eels in very poor condition), such eels are no longer seen. Stocks of longfins have become

Photo **A large (1.45 m, 12.5 kg) migratory female longfin eel from Te Waihora.** Photographer **Greg Kelly, NIWA.**

reduced within the lake, and reserve areas (adjacent to mouths of the Selwyn River, Harts Creek, Irwell, and LII) are important refuges for this species.

Flounders

There are no specific TACCs set for the lake as it is part of Fishstock FLA 3 (east coast and southern South Island). Also, for fishery management purposes, all species of flatfish are combined into a generic species code. The lake flatfish stocks are usually dominated by black flounders, and the availability of flounders reflects lake opening regimes, and the success of New Zealand-wide spawning of the three main species (blacks, sands, yellowbellies).

Yelloweye mullet

Mullet are also a quota species, but Te Waihora/Lake Ellesmere is part of Fishstock YEM 3, east coast South Island. Stocks will reflect favourable opening times for entry of juveniles and pre-spawning adults, usually in spring-early summer.

Key indicators of change

Eels

The commercial fishery is mainly monitored via trends in size and CPUE. Establishing annual recruitment indices would be a significant advance, as would developing an index of the number of migrating female eels of both species. Customary harvest "satisfaction" will be evaluated via a customary indicators survey presently underway. Increased numbers of longfins would be an important biodiversity measure.

Flounders

Recruitment index monitoring is needed to predict future yields-annual variability in catch indicates the dynamic nature of the fishery.

Key drivers

Satisfactory recruitment of eels, and especially flounders, is dependent upon a suitable spring lake opening regime. Invertebrates, especially chironomid midge larvae, are the primary food source for juvenile eels, and flatfish (Kelly and Jellyman 2007), so maintaining water quality conditions that promote production of midges is critical. Higher summer lake levels would reduce the likelihood of excessive summer water temperatures, while maintaining larger marginal foraging areas for eels. At present, flounders die in set nets if there is a prolonged spell of calm weather that results in low levels of dissolved oxygen. Commercial fishery harvests, and targeted customary fishing of migrating eels, can influence the numbers of female eels that successfully migrate each year.

Management goals

The eel fishery must be managed sustainably; periodic adjustments to the TAC may be necessary, depending on recruitment strength, growth, and mortality (mainly fishing mortality). Spring opening of the lake is essential to enable recruitment of key species, while an autumn opening (mid March-May) would allow escapement of migrating female shortfins and longfins of both sexes. Consideration should be given to a nil harvest for longfins.

The present fish species diversity, both within the lake and tributaries, should be maintained, and preferably enhanced. The pros and cons of attempting to re-establish macrophyte beds should be evaluated, and, depending on the outcomes, a trial area established. Greater protection should be afforded to remaining wetland areas, and consideration given to establishing new areas by inundation of low-lying margins and suitable sections of tributaries. Habitat for rare species like giant kokopu should be enhanced. Reduced nutrient loads to the lake might reduce the probability of future blooms of blue-green algae (small blooms occur, but not to the extent they occur in Wairewa with attendant fish and stock deaths).

Photo **Black flounder provide the bulk of the commercial flatfish fishery catch, but sand flounder** Top **and yellowbellies** Bottom **are also important** Photographer **Shelley McMurtrie.**

Required management actions

Establishing a regular spring opening regime is of major importance. There needs to be resolution of management "overlaps" between stakeholders and crown agencies, notably Ngāi Tahu and the Ministry of Fisheries. Likewise, the merits and feasibility of attempting to re-establish significant macrophyte beds needs to be evaluated.

5.8 Acknowledgments

Thanks to Nigel Scott, Ngāi Tahu, for the information on customary harvest. Trevor Gould, Ross Wilson, Gary Pullan, and Frank Lambie provided useful comments about historical aspects of the commercial fisheries.

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ROSS NOVIS

06

BROWN TROUT fishery

ROSS MILLICHAMP Fish & Game North Canterbury

The Te Waihora/Lake Ellesmere brown trout fishery is one of the most degraded in New Zealand. There are fisheries with fewer fish, but Te Waihora/Lake Ellesmere stands alone in terms of the extent to which the fishery has changed. A range of natural and human-induced factors are likely to have contributed to the decline but it is difficult to single out a primary cause. Restoration of the fishery is possible given the will to do so, but the target for restoration needs to be carefully considered. The restoration of the fishery to 1940s levels is unlikely to be achievable but restoration to early 1980s levels is achievable and would deliver considerable benefits to the community

6.1 Introduction

The brown trout (*Salmo trutta*) fishery of Te Waihora/Lake Ellesmere had a reputation as one of the world's best in the 1920s and 1930s. Over the following decades the fishery slowly declined, in fits and starts, and is now highly degraded and of limited local value. In this paper I present the issues, explain the context to these issues and suggest some future management actions which might contribute to restoration of this fishery.

6.2 History of the golden years

Brown trout were introduced to the Te Waihora/Lake Ellesmere system in 1868 and a very productive fishery quickly became established. Hardy (1989) proposed that:

> *"arguably, nowhere in New Zealand has the brown trout thrived better, and been more successful in establishing a large population of large sized fish than in the Ellesmere catchment-particularly in Ellesmere itself."*

The final few words of that statement are particularly important because while other Canterbury lowland fisheries appear to be reliant on ocean production, Te Waihora/Lake Ellesmere seemed to rely heavily on production within the lake.

The success of the Te Waihora/Lake Ellesmere brown trout fishery has been put down to a number of factors:

Access to the ocean

The presence of a large population of trout which spend part of their lives living in the ocean off the Canterbury coast has undoubtedly made some contribution to the fishery. These fish migrate through the cut when the lake is open to the sea. Trout also move from headwater spawning grounds to the lower reaches, estuary and ocean after spawning, seeking out warm water and an abundant food supply to allow them to recover from the rigours of spawning. In most Canterbury rivers it is likely that the available habitat in the typically small estuaries is quickly exhausted and most fish move into the ocean during this phase of their life cycle.

The extent to which sea run brown trout contribute to the productivity of low country fisheries in New Zealand is poorly understood. However a tag/recapture study conducted by the North Canterbury Acclimatisation Society in the 1962 and 1963 seasons showed that 15% of trout tagged at the Selwyn Trap and later recaptured by anglers, were re-captured outside of the Te Waihora/Lake Ellesmere catchment.

Lake habitat

The weed beds of Te Waihora/Lake Ellesmere were thought to provide exceptional shelter, protection and feeding opportunities for young trout. The importance of Te Waihora/Lake Ellesmere to the trout fishery was summed up by Percival (1932) who stated that:

> *"The Lake forms a magnificent reserve where the fish may be safe from the angler and where they may grow".*

The presence of significant lowland freshwater/estuary habitat made Te Waihora/Lake Ellesmere unique and meant that trout that were recovering from spawning may not have needed to move into the ocean. Hardy (1989) found that:

> *"an opening of Lake Ellesmere to the sea at a particular time of year is unlikely to be critical to the maintenance of brown trout populations of the Ellesmere catchment, except insofar as appropriate openings influence the migrations and abundance of the native fish forage species upon which trout feed".*

Tributary feeding and spawning habitat

Te Waihora/Lake Ellesmere tributaries also once provided excellent habitat for trout. Throughout spring and summer large numbers of trout moved from the lake to the lower reaches of tributary streams to feed. It is presumed that they were following populations of native fish species which were entering the rivers to spawn. Trout feeding would be more effective in the tributary streams than in the lake because the prey would have been easier to see due to the improved visibility of the water, and more densely concentrated due to the smaller size of the water bodies.

As summer came to an end the trout moved upstream out of the lake and from lower reaches of tributary streams to seek reaches with clean gravels and clear water in which to spawn. In smaller streams such as the Doyleston Drain and Boggy Creek, spawning took place within 10-20 km of the lake. However, in the Selwyn River, trout migrated up as far as the foothills to spawn. Access to permanent water in the foothills is the major point of difference between the Selwyn and other Te Waihora/Lake Ellesmere spawning streams, and may be the reason it is the most important.

Most estimates of the size of the Te Waihora/Lake Ellesmere trout fishery have been obtained by counting spawning trout in the lower Selwyn River. The fishery was probably at its peak during the 1940s when the North Canterbury Acclimatisation Society (the predecessor of Fish & Game New Zealand) estimated the spawning population of the Selwyn River at 65,000 trout. Although the Selwyn is undoubtedly the most important tributary for brown trout spawning, that estimate only relates to a portion of the total Te Waihora/Lake Ellesmere fishery, and comes at a stage of the life cycle when the portion of the run which is caught by anglers and commercial fishermen (as bycatch) has already been removed. The entire Te Waihora/Lake Ellesmere brown trout fishery could conceivably have constituted 100,000-200,000 adult fish at this time.

Such was the productivity of the Te Waihora/Lake Ellesmere brown trout fishery that it was used as a hatchery for stocking other fisheries. Professor Percival was quoted in Lamb (1964) as saying "enough fish could be salvaged from the Selwyn in a season to stock all rivers in the South Island".

A fishery of this scale attracts considerable angler interest and provides significant amenity values. Hardy (1989) suggested that the Te Waihora/Lake Ellesmere trout fishery ranked second in popularity and usage (to the Waimakariri) in the North Canterbury Acclimatisation Society district. In order to put this into context, robust assessments of angler usage conducted in 1995 and 2001 (Fish & Game NZ National Angler Survey) found that the Waimakariri was the most heavily fished river in New Zealand. Teirney et al. (1987) estimated that anglers made

55,800 visits to Te Waihora/Lake Ellesmere and its tributaries during the 1975/76 and 1978/79 seasons, at a time when the fishery had already started to degrade.

National Angling Survey data indicates an ongoing downward trend in angler use of the catchment:

- 1994-95: 12,920 +/- 2,080 angler-days (Unwin and Brown 1998)
- 2001-02: 3,780 +/- 660 angler-days (Unwin and Image 2003)
- 2007-08: 2,770 +/- 530 angler-days (M. Unwin, NIWA, pers. comm. October 2008).

Recreational fishing was largely focused on the lower reaches of tributary streams where the fish were found in dense concentrations. Fishing often took place during the hours of darkness when the trout came out from the shelter of undercut banks or riparian vegetation to feed in the shallow water where the prey species were congregating. The fishery provided excellent angling opportunities throughout the duration of the October to April open season.

6.3 The decline of the Te Waihora/Lake Ellesmere brown trout fishery

The Te Waihora/Lake Ellesmere brown trout fishery has undergone a dramatic decline since the 1940s. The decline can be broken into two distinct phases; the decline which took place immediately after the Wahine Storm, and the more gradual decline which has taken place over the last 20-30 years.

Figure 1 shows the change in the number of trout spawning in the Selwyn River as estimated by a series of census traps operated by the North Canterbury Acclimatisation Society and the North Canterbury Fish & Game Council since 1941. These traps involve a considerable operational effort and were operated at infrequent intervals so there are significant gaps in the data. However, for the purpose of this paper, the period between 1941 and 1977 can be considered the "post-Wahine" phase and the period between 1977 and 2007 the "latter" phase.

The inclusion of pre-1977 data in Figure 1 hides the size of more recent declines, because of the scale on the y-axis. Figure 2 gives a better indication of the change in trout returns in the second phase of the decline.

Angler activity is another useful way to document changes in fish populations. Anglers are highly mobile and make decisions on which water to visit based partly on the number of fish that a particular fishery offers. However, there is likely to be a time lag between a reduction in fish numbers and a reduction in angler use, as anglers who have a lifetime of association with a fishery take time to accept that the changes they are observing are permanent. There are very few estimates of angler use of Te Waihora/Lake Ellesmere available (see Figure 3), especially for the period prior to 1977.

The phase of fishery reduction which took place after 1968 is presumed to relate to the devastating effects of the Wahine storm, in April of that year, which destroyed beds of aquatic macrophytes such as *Ruppia* and *Potamogeton pectinatus*. The loss of permanent weed beds led to increased erosion of the lakeshore due to a loss of the "breakwater" effect, increased erosion of the lake bed by wave action and an increase in the amount of suspended sediment in the water column of near-shore lake waters.

The second phase of reduction in the trout fishery was less spectacular in terms of absolute numbers but may be more significant in terms of its impact on anglers. The post Wahine storm phase appears to have been associated with a further substantial reduction in the number of trout available

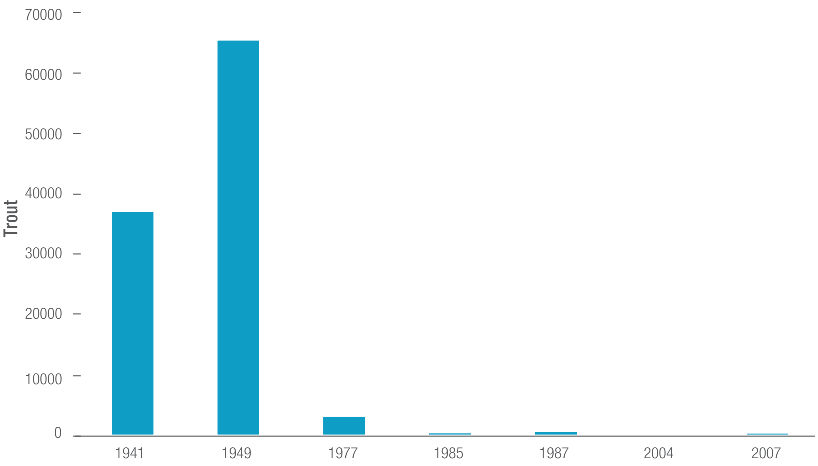

FIGURE 1. Estimates of the Selwyn River brown trout spawning runs from census traps, 1941-2007.

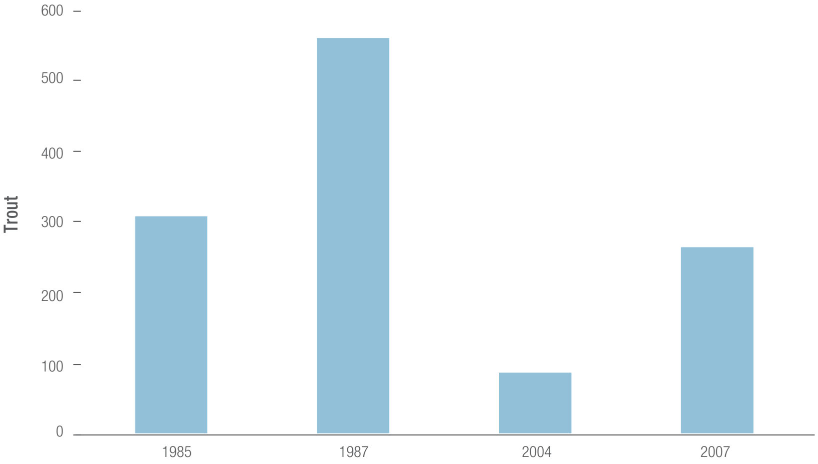

FIGURE 2. Estimates of the Selwyn River brown trout spawning run from census traps, 1977-2007. Please note that the 2007 census was conducted downstream of previous sites and reflects close to total spawning escapement for the Selwyn River.

to anglers. Figure 3 shows the Te Waihora/Lake Ellesmere fishery still attracted very considerable angler effort at this time and was still in fact the most popular trout fishery in the North Canterbury region. Only the salmon fisheries of the Rakaia and Waimakariri rivers attracted more angler interest in the region. The fishery continued to provide significant (albeit reducing) angler opportunity as late as the mid 1990s but has now declined to being of local significance only. The major factors in play during the second phase of fishery reduction were a reduction in tributary flows and increased intensification of land use in the catchment.

In 2003 NIWA conducted a study of anglers' perceptions of changes in the state of lowland river trout fisheries throughout New Zealand over the previous 20 years and concluded that Canterbury's fisheries were amongst the most degraded in the country. The Selwyn River was identified by the authors as being a "river showing a marked decline in angling quality" which the anglers put down to "low flows due to excessive water abstraction for irrigation" (Jellyman et al. 2003). Anglers also indicated that they had observed deterioration in spring-fed Canterbury streams where flows had remained stable but water quality was perceived to have deteriorated.

Possible causes of the decline

Although there do appear to be two phases to the decline of the Te Waihora/Lake Ellesmere trout fishery, it is difficult to single out a predominant cause. Hardy (1989) proposed 10 possible explanations but concluded that were was insufficient scientific information available to narrow them down beyond that. Main and Glennie (1996) took a fresh look at the issue and proposed 11 possible explanations. They concluded that the loss of macrophtye beds and bycatch by commercial fishermen were likely to be the major factors.

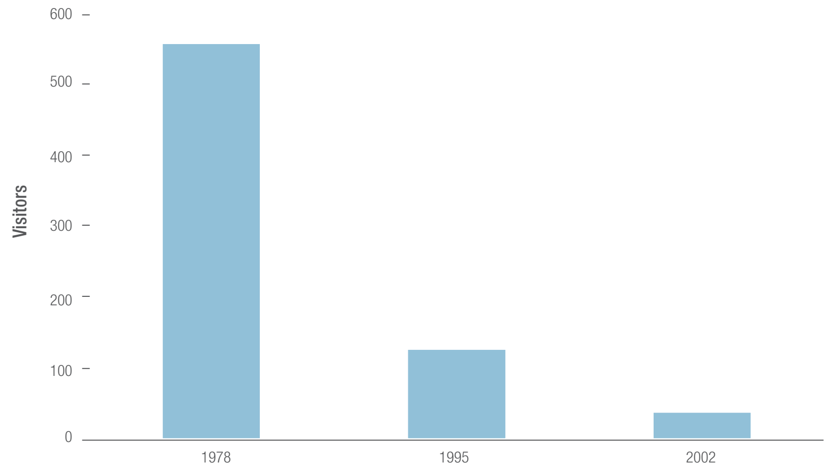

FIGURE 3. Estimates of angler days spent in Te Waihora/Lake Ellesmere and its tributaries in the 1977-78, 1994-95 and 2001-02 seasons (Teirney et al. 1987), (Unwin & Brown 1998) and (Unwin & Image 2003).

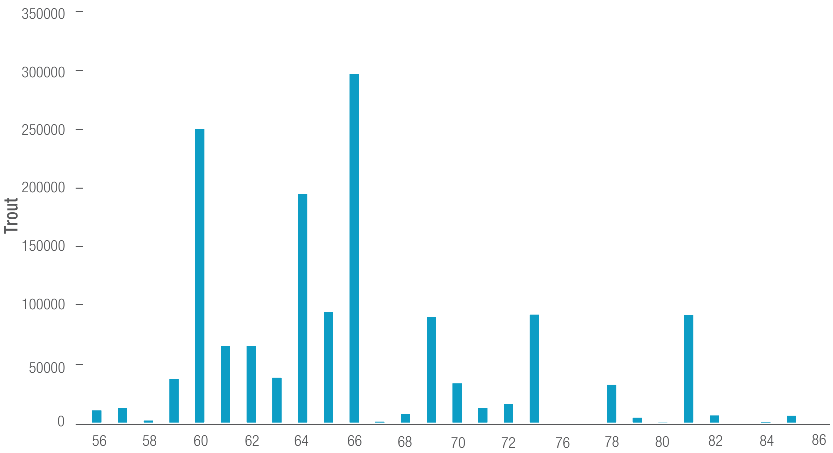

FIGURE 4. North Canterbury Acclimatisation Society trout salvage records, Te Waihora/Lake Ellesmere catchment, 1956-1986.

In 2007 the list of possible causes is strikingly similar to those proposed in the past:

Commercial fishing

The mortality of trout caught as bycatch by commercial fishermen has been identified as a major factor affecting trout abundance in the past. It is thought that trout generally survive capture in fyke nets set for eels, but die when caught in the gill nets set by flounder fishermen. Glova and Todd (1987) claimed that:

> *"over the years the cumulative loss of adult trout in this manner (gillnetting for flounders) is believed to have had a major impact on stocks in the lake, and may well be the single most important factor in the decline of this once abundant sport fishery."*

Despite long-term concerns about the impact of commercial fishing on the Te Waihora/Lake Ellesmere trout fishery, no records exist of how many are actually caught.

It is reasonable to expect that as trout numbers in the lake have declined, the impact of bycatch should have reduced. However, even if bycatch is no longer a significant factor, it could still act as a barrier to fishery restoration in the future. There is little point in undertaking comprehensive programmes targeted at improving the trout fishery only to have them caught as bycatch before becoming available to recreational anglers or to future generations through spawning.

Spawning habitat

Trout require habitat of particularly high quality for spawning. The water needs to be clear and well oxygenated, and the stream bed needs to consist of loose gravel with minimal sediment content. This is often the first sort of habitat to disappear as stream water quality and quantity become degraded. Taylor and Good (2006) conducted a comprehensive survey of trout spawning in the lower reaches of the catchment (east of SH1) and compared the results with those of similar surveys by the North Canterbury Acclimatisation Society in the 1980s. They found that spawning activity had reduced by 63% in that time, and in some streams had disappeared altogether. Reduction in spawning can reflect either a general decline in the number of fish in the fishery or a reduction in the quality of the spawning habitat. Taylor and Good were of the view that degradation in the quality of the spawning habitat due to stock access, sedimentation and a reduction in surface water flows, were the principal causes of the observed decline.

Loss of access to the Selwyn River headwaters

In the past trout migrated up and down the Selwyn River whenever flows allowed. The largest migration took place in early winter as trout attempted to reach permanently flowing headwater spawning reaches. Once spawning was complete adult trout would attempt to migrate back down the river to the lower reaches and lake. Another migration took place as young trout grew and saturated the available habitat in the headwater reaches and surplus fish were pushed out and forced to migrate downstream, eventually reaching the lake.

Trout access to the headwater reaches of the Selwyn River has invariably increased the production of the fishery, particularly for adult spawning and juvenile rearing. The Selwyn River has always been subject to drying in the middle reaches and these migrations were full of risk. North Canterbury Acclimatisation Society and North Canterbury Fish & Game Council records indicate that hundreds of thousands of trout were salvaged by staff and volunteers between 1936 and the present day. Most of the fish which became stranded were fry or yearlings which were moving through the middle reaches during the summer when the river was drying.

Figure 4 shows that trout salvage is highly variable, depending on river flows during critical migration months and staff availability to do the work. It can be assumed that many fish died before they were able to be salvaged and that some of the salvaged fish may not have survived the stressful experience.

Theory relating to standard stock recruitment curves predicts that although trout spawning activity in a catchment can be highly variable, the production of juvenile trout is likely to be relatively constant, because increased spawning activity leads to increased mortality on the spawning grounds and the “output” of young remains constant. If this is the case in the Te Waihora/Lake Ellesmere tributaries, it can be assumed that in the years when salvage was low, 100,000-300,000+ young trout were successfully migrating down the catchment each year over summer. In order for the migratory behaviour to continue, the benefit to the population of having access to the headwaters for spawning must have exceeded the loss incurred in the years when the young fish became stranded on their downstream migration.

The pattern of migration through the Selwyn appears to have now changed. In recent years Fish & Game staff have visited drying reaches of the Selwyn River as it recedes during the summer and found very few fish to salvage. This suggests that trout may have stopped migrating and may no longer be utilising the upper reaches of the catchment. This could be occurring because winter flows are no longer sufficient to allow adult trout to migrate to and from the headwaters to spawn, and/or because summer flows no longer allow young fish to successfully migrate downstream. Interpretation of the data in Figure 4 suggests that the Te Waihora/Lake Ellesmere trout fishery was able to withstand significant mortality amongst young fish in relation to headwater spawning at frequencies of one year out of four, or one year out of five during the 1950s, 60s, 70s and 80s. However, the flows that cause those losses have occurred more

Photo **Ross Millichamp with a 4.5kg sea run brown trout caught at the Rakaia River mouth. Similar fish do run into Ellesmere but their contribution to the fishery is unclear.** Photography **Helgie Henderson.**

frequently in recent years and it is possible that headwater spawning is now doing the population more harm than benefit and that the migratory behaviour has stopped.

If the loss of headwater spawning is considered alongside the reduction in low country spawning identified by Taylor and Good (2006), it is highly likely that the Te Waihora/Lake Ellesmere trout fishery is suffering from a lack of juvenile spawning and rearing habitat.

Loss of rearing habitat in Te Waihora/ Lake Ellesmere

Past reviewers have identified that the change in Te Waihora/Lake Ellesmere habitat that followed the Wahine storm is a major factor affecting trout populations. Although the lake has always been turbid, prior to the Waihine storm there were parts of the lake where the water was clear, such as around inflowing streams and between weed beds and the shore due to the "breakwater" effect. Although the areas of clear water were limited in size, they would have collectively added up to a considerable amount of habitat for trout and their prey.

Hardy (1989) analysed North Canterbury Acclimatisation Society records and found that catch per unit effort at census fish traps had remained constant between the 1940s and the 1960s, but plummeted in 1971. A lag of three years between the Wahine storm and a reduction in the trout spawning run can be explained by the fact that most trout first spawn at three years of age. The fact that the storm and collapse happened in sync with each other suggests that lake habitat remains a major contributor to the current state of the trout fishery.

Hardy (1989) proposed that the weed beds were of particular importance to young trout who were reliant on them for food and shelter during the early parts of their lives when they were vulnerable to predation and reliant on insects and very small fish (which tended to live around the weed beds) for food. When the effect of the loss of this habitat of high importance to young trout is considered alongside the loss of young trout habitat in the Selwyn River (see above), it is highly likely that the catchment is suffering from a lack of juvenile rearing habitat.

Reduction in frequency of lake openings

Environment Canterbury staff advise that there has been a reduction in the frequency of lake openings in recent years. In the past when the lake was the principal rearing water body in the catchment, access to the ocean was probably unimportant. However, if the lake is no longer providing the quality of trout habitat that it did in the past, access to the ocean is likely to be more important. The timing and duration of lake openings is likely to be more critical to the trout population than the absolute number of openings. If the pattern of trout movement through the mouth of the nearby Rakaia River is taken as a guide, the ideal time for Te Waihora/Lake Ellesmere openings is between mid October and mid January. Many anglers believe that trout enter coastal rivers and lakes to feed on whitebait but in my experience the main runs do not occur until the much bigger runs of Stokells smelt arrive after the main run of whitebait.

Although the modification of the lake opening regime is one of the management actions proposed to address the state of the trout fishery, it is likely that the recent reduction in lake openings has not been a major contributor to the current problem.

Factors unlikely to have caused the decline in the trout fishery

Three factors, often debated in terms of their potential contribution to the demise of the trout fishery, are probably relatively unimportant but do need to be discussed.

Recreational harvest

There is no doubt that anglers once removed a very large number of trout from the Te Waihora/Lake Ellesmere system. At the time when the fishery was at its most productive, catch and release was not commonly practiced by anglers and most of the fish that were caught were killed. However, if over-harvest were an issue, the fishery ought to have recovered by now in response to the significantly reduced angler pressure it now receives (Figure 3).

Lake water quality

Trout do not generally do well in eutrophic conditions, principally because they require highly oxygenated water. Elevated nutrient concentrations generally lead to increased plant photosynthetic activity and reduced oxygen in the water column. Te Waihora/ Lake Ellesmere is one of the most eutrophic lakes in New Zealand but is unusual because the amount of sediment carried in the water is so high that photosynthesis is depressed and oxygen levels remain high. However if weed beds are re-established and water clarity improves, water quality could limit the recovery of the fishery-this hypothesis clearly needs further investigation.

Food supply

Although the lack of weed beds may be restricting the availability of food and cover for young trout, it appears unlikely that food is restricting the growth of large trout. There still appears to be an abundance of native fish which is the principal prey of large trout, and trout that are caught by anglers in Te Waihora/Lake Ellesmere are always in exceptional condition.

Photo **Fish & Game staff salvaging trout from an isolated (landlocked) pool in the Selwyn River.**
Photography **Brian Ross.**

6.4 Suggested management actions

In order to determine the most appropriate management action to restore the Te Waihora/Lake Ellesmere trout fishery, it is important to be able to identify the predominant cause of the decline. Like past reviewers, I am unable to pinpoint a single factor which has caused the decline in the fishery. In fact it is highly unlikely that the fishery has declined due to a single factor and more likely that it is in response to a combination of factors. Jim Lichatowich sums it up in his book "Salmon Without Rivers" where he writes :

> *"Salmon depletion is nearly always the result of cumulative stresses on the fish's life cycle in the river, estuary and ocean. In healthy, resilient ecosystems, stresses are absorbed with little discernable change in gross measures of production. As stresses accumulate, however, the resiliency of the ecosystem is slowly and invisibly lost. At some point, one more stress causes the catastrophe."*

Restoration of the Te Waihora/Lake Ellesmere brown trout fishery will require action on a broad front. Over time we may come to better understand the importance of the various factors discussed and may even be able to dismiss some altogether. However, at the start we should attempt to address all potential factors and adapt the programme as our knowledge improves.

It is also important to establish a realistic target for fishery restoration. Although restoration of the fishery to 1940s levels may be possible in time, it would be better to start with a target such as restoration back to early 1980 (post-Wahine) levels.

The following management actions are suggested:

Lake opening regime

If the quality of the lake environment can be improved to such an extent that it provides quality trout habitat, then the lake opening regime may be irrelevant. However in the short and medium terms it is a very important management action. The continued productivity of the nearby Rakaia River sea run trout fishery indicates that the local ocean environment does have something to offer the Te Waihora/Lake Ellesmere population. In order to assist the establishment of a truly sea run fishery in Te Waihora/Lake Ellesmere, the lake needs to be open to the sea for as long as possible between mid October and mid January to allow adult fish to enter the lake from the ocean. The number of days the lake is open to the sea is more important than the number of times the lake is opened. A permanent outlet to the sea would be the best action but it is recognised that this may not suit other lake species. However a programme of more frequent openings during spring and summer would be of benefit.

Commercial bycatch

Research needs to be conducted to document the level of bycatch which is taking place and the effect it is having on the trout fishery. Reviewers have been suggesting that this is a likely cause of trout decline for close to twenty years and we are yet to even start gathering data on capture rates. This action would have to be undertaken by the Ministry of Fisheries (MFish) as part of their routine fishery reporting program. Once data on trout capture rates were gathered, NIWA could be commissioned to give advice on the likely impact to the fishery. If a significant impact was determined, MFish could introduce rules governing the way that commercial fishing took place to reduce the bycatch to acceptable levels.

Spawning stream restoration

Taylor and Good (2006) made 12 recommendations to Environment Canterbury about actions that could be taken to address the degradation and loss of spawning habitat that has occurred in recent years. They gave examples of two places where riparian management had improved and spawning numbers were higher than historical levels, which gives some confidence that action will deliver tangible results.

Restoration of Selwyn River flows

Adult trout in the lake and lower reaches need to regain access to the upper Selwyn River catchment for spawning, and juvenile trout need to regain access to the lower reaches and lake for growth. It is unrealistic to expect this to happen every year but it needs to take place three years out of four, or four years out of five. At present trout are being prevented from migrating through the catchment by the impacts of abstraction and climate. Abstraction is the only one of these factors that can be managed and so consent conditions should be reviewed to ensure that the actions of abstractors do not prevent trout from being able to migrate through the system. A number of reviews of groundwater and surface water consents are already underway but may not be targeted at achieving this standard.

Restoration of weed beds

This is clearly a long-term target but a start needs to be made. The theory that weed beds can be reestablished needs to be tested and used as a justification for further work, or the abandonment of the concept.

Juvenile recruitment

Many of the actions listed above are targeted at improving conditions for the incubation, hatching, rearing and growth of juvenile trout, on the presumption that once they get past a certain critical size, there will be suitable feeding and growth opportunities available to take them through to maturity. This theory should be tested by releasing hatchery reared trout into the lake and monitoring their returns. This was attempted on a small scale by NIWA in the early 1990s and although there was difficulty in tracking returns, Glova (1996) concluded that:

> *"releasing hatchery reared trout of around 50 g in weight in the Lake Ellesmere system is a viable option for enhancing the fishery".*

Research

In 1989 Hardy conducted a comprehensive review of the state of knowledge of the Te Waihora/Lake Ellesmere fishery and concluded that there were large information gaps that needed to be plugged before the true cause of the observed declines could be identified. Main and Glennie (1996) concluded something very similar as little had been done in the intervening period. In 2007 I have again come to the same conclusion. If research is not undertaken to resolve these issues then attempts at restoration are likely to be slow, reactive and unlikely to succeed. Statutory agencies need to co-operatively develop a research strategy for the lake and seek funding from the crown to undertake it.

Photo **Brian Ross from Fish & Game, loads brown trout salvaged from the Irwell River, into a fish transporter for relocation to permanent water.** Photography **Ross Millichamp.**

6.5 Conclusions

The restoration of the Te Waihora/Lake Ellesmere brown trout fishery will be a challenging but ultimately rewarding task. The cause of the collapse is likely to be a combination of natural and human-induced factors, but manipulation of the latter, which include commercial fishing, irrigation, land use intensification and riparian management practices, are the only management actions available to us.

Although the fishery is highly degraded compared to its heyday in the first half of the 20th Century, there is still a significant stock of fish in the catchment from which a recovery could emanate. More than 300 trout ran up the Selwyn River to spawn in 2007 which indicates that although the recreational fishery is highly degraded, the population is far from becoming extinct. Taylor and Good (2006) identified around 500 trout redds in other spawning streams and found that spawning was concentrated in waters where restoration programmes were already underway.

Some people may not see the restoration of the Te Waihora/Lake Ellesmere brown trout fishery as a priority, especially if it comes at a cost to agricultural production in the catchment. However, it is important to remember that trout are a vital indicator of lake health, given that they are highly visible and have a strong recreational following. If the trout fishery can be restored, many of the other lake species will likely be restored also.

The real finding of this process is that similar reviews of lake values have taken place in the 1980s and 1990s but no commitment was made to resolving the issues and the lake has continued to degrade. This should not happen again.

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07

BIRDLIFE of the lake

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Te Waihora/Lake Ellesmere is a large brackish and low-lying lake in Canterbury. It is widely regarded as a wildlife habitat of national and international importance with the highest recorded bird diversity of any location in New Zealand. Apart from the diverse range of habitats and species characterising the lake there are very large numbers of some species including those of conservation concern such as banded dotterel and Australasian bittern. The lake and its environs are hugely modified with habitat loss still occurring. A range of indicators of change in the state of wildlife of the lake have been identified. Evaluation of changes to these indicators, especially over the last 10-20 years indicates that some indicators are healthy and some likely suffering slow decline. Four principal outcomes and 10 core management actions are proposed in order to safeguard the wildlife features of the lake and its environs. The outcomes are associated with maintaining species diversity, enhancing the populations of key conservation and taonga species, sustainably managing harvest species for both recreational and Ngāi Tahu reasons, and providing an appropriate habitat mix for all of the above. Key management actions related to these outcomes are associated with lake level operating regimes and targeted habitat protection.

7.1 Introduction and aims

Te Waihora/Lake Ellesmere is widely considered one of the most important wetlands in NZ, especially for its wildlife (see O'Donnell 1985, Taylor 1996). In this assessment we consider:

- The context of, and knowledge base for, management of the wildlife of Te Waihora/Lake Ellesmere, including an assessment against relevant material from the Taylor (1996) Natural Resources of Lake Ellesmere (Te Waihora) and its Catchment report (Section 7.2);
- An approach to defining draft wildlife outcomes and proposed indicators of change (Section 7.3);
- Key values, important habitats and some proposed wildlife outcomes reflecting future management goals (Section 7.4);
- Key indicators of the ongoing change, related to the proposed outcomes and reflecting bicultural views, of the state of Te Waihora/Lake Ellesmere wildlife (Section 7.5);
- The changing state of Te Waihora/Lake Ellesmere wildlife (and its proposed indicators), from pre-Maori times to the present (Section 7.6);
- The relationship of indicator change to lake level and other forms of management, i.e., the key drivers of wildlife change (Section 7.7); and given the above;
- Ongoing management requirements, including specific projects, benefits and costs, in priority order (Section 7.8).

Finally, a short discussion precedes a set of conclusions which in turn are followed by overall report recommendations.

7.2 The context of, and knowledge base for, wildlife

Much has been published about the wildlife of Te Waihora/Lake Ellesmere (e.g., Stead 1932, O'Donnell 1985, Taylor 1996, Sagar *et al.* 2004) and there is much related ongoing 'research' (e.g., biannual Ornithological Society of NZ (OSNZ) wader counts since Nov-Dec 1983), Fish and Game North Canterbury, and now Christchurch City Council, surveys). Probably the most integrated publication covering all this work is that of Taylor (1996). That work reported and summarised the following:

- Species presence and habitat needs, including a summary of bird population characteristics, organised by waterfowl, waders, swamp birds and other species. Data in the report are however dated, i.e., it relied on work undertaken and reported on between 1985-87. In summary it was noted that 161 species (as of 1987) have been observed at the lake or in its immediate environs (DoC 1987), with around 80 species being regular inhabitants (O'Donnell 1985).
- Habitats and values, organised around geographical segments of the lake and its environs (including Kaitorete Spit) (see Figure 1).
- The significance of Te Waihora/Lake Ellesmere - that report summarised the recommendation for designating Te Waihora/Lake Ellesmere as a wetland of international importance (IUCN 1981) but noted that further progress would not occur until Crown and Ngāi Tahu Treaty negotiations had been completed. With the establishment of the Joint Management Plan between Ngāi Tahu and DoC it might be envisaged that some progress will shortly occur in this area.

Implications for management, particularly in relation to lake level changes, eutrophication, foreshore erosion, recreation and drainage and foreshore development, were also given. The report summarised the purpose and implications of the current lake operating regime, including the Water Conservation Order (Lake Ellesmere) 1990 provisions.

Apart from the ongoing bird survey work we are aware of only one new study (Sagar *et al.* 2004) that provides additional habitat related management information post Taylor (1996). This work reports primarily on the feasibility of re-establishing the macrophyte beds in the lake but also notes a possible and relatively recent change in the food chain of the lake, notably the shift from an invertebrate fauna where aquatic snails

Photo **Large flocks of 50-150 of Royal Spoonbills are now a relatively common sight.** Photography **Colin Hill.**

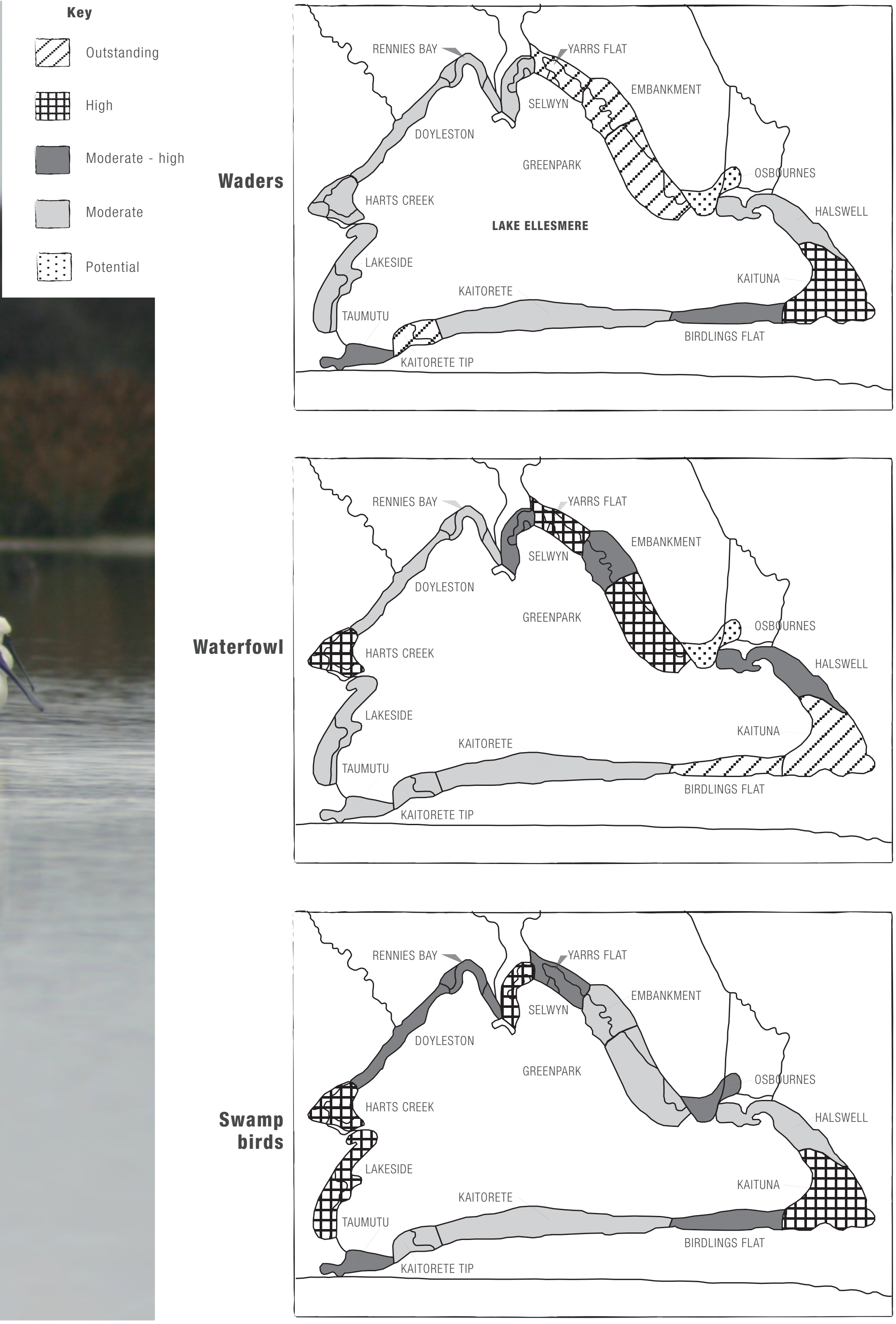

FIGURE 1. Wildlife values[1] and key habitat areas around Te Waihora/Lake Ellesmere. Source (O'Donnell 1985).

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[1] During the late 1970s and early 1980s the New Zealand Wildlife Service undertook the first national inventory of habitats of significance to wildlife, termed Sites of Special Wildlife Interest (SSWIs). Habitats were rated as being of "Outstanding", "High", "Moderate-high", "Moderate", or "Potential" value for species protected by the Wildlife Act 1953. Sites were assessed according to 16 criteria. The criteria used were based on criteria used by the International Ramsar Convention for identifying Wetlands of International Importance at the time, for which New Zealand has been a contracting party since 1976. The Convention on Wetlands, signed in Ramsar, Iran, in 1971, is an inter-governmental treaty which provides the framework for national action and international co-operation for the conservation and wise use of wetlands and their resources.

were very important to one dominated by chironomids. Little is understood about the dynamic variability in production of chironomids and how this might be affected by changes in lake management, especially around for example, salinity.

Bearing these issues and findings in mind an assessment of the information available, as summarised above, in association with relevant expert knowledge and discussions with the tangata whenua and other expertise should suffice in defining preliminary desired management outcomes for the wildlife of Te Waihora/Lake Ellesmere.

Photo **Godwits, while present in most years at the lake, visit only in relatively low numbers.** Photography **Colin Hill.**

7.3 Approach to defining outcomes and indicators of change

Overall, the quality of information about Te Waihora/Lake Ellesmere wildlife is very high (see Section 7.2). Published and unpublished data have been relied upon with no new field work undertaken. Fortunately the Ornithological Society of NZ (OSNZ) and Fish and Game North Canterbury (for game bird species) undertake frequent surveys of the lake's wildlife and these resources are heavily relied on for this report; additionally, since 2006 the Christchurch City Council has begun annual surveys of the lake wildlife. Discussions have occurred with key wildlife scientists who have had long associations with wildlife surveys of the lake (e.g., B. Ross of Fish and Game North Canterbury and P. Sagar of NIWA), with representatives of Ngāi Tahu about key species and changes over time, and with Colin Hill a landowner with long-running interest in wildlife conservation. All of these discussions have also focused on the choice of 'desired outcomes for wildlife' and the subsequent selection of a range of ongoing wildlife-related indicators for future monitoring of change related to key management objectives, and ultimate reporting thereon. The framework for the report is therefore as follows:

SECTIONS AND STEPS		METHODS/PROCESS
Section 7.4-7.6		
Outline the wildlife values of the lake and proposed desirable outcomes	>>	Review literature; gather unpublished data from agencies and experts; discussions
Identify indicators of change	>>	Review literature, discuss with agencies and experts; but also selected against SMART criteria
Using the indicators evaluate the state of wildlife at the lake	>>	Use literature and any available data
Section 7.7		
Identify the key drivers of change to these indicators	>>	Literature review; discussion with experts
Section 7.8		
Suggest interim management actions that reflect measures to achieve the outcomes and which can be reported against using the indicators	>>	Liaise with Ngāi Tahu, DoC and Fish and Game, discuss with experts, consult with other stakeholders

7.4 Wildlife values, key habitats and proposed desired wildlife outcomes

Values and habitats

From the key literature (e.g., O'Donnell 1985, Taylor 1996) it is clear that the key scientific 'values' of the lake's wildlife are:

- A very high level of species diversity (N=110 indigenous bird species that use the lake and its riparian margins for feeding or breeding), represented within a range of guilds[2], including international migratory species. Sagar *et al.* (2004: 38) note that the total number of species recorded at the lake is 167 species - given a total number of extant bird species in New Zealand of 324 recorded in 1996 then at least 50% have been recorded from the lake. This proportion is far more than for any other site in New Zealand;
- Very large numbers of birds (up to 98,000 recorded at one time), especially waterfowl;
- Comparatively large numbers of some species which rely on the lake for particular life stages (e.g., southern crested grebe, bittern, banded dotterel);
- Comparatively large proportions of the numbers of some species using New

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[2] A guild is defined as a community of (in this case bird) species with similar habitat requirements (Verner 1984).

Zealand wetlands as over-wintering sites during migration (e.g., wrybill, pied stilt).

These values contribute to the lake being considered as nationally important for wildlife (O'Donnell 1985) because:

- A very large number of birds occur there at all times
- There is a very high species diversity across a wide range of guilds
- There are significant proportions of New Zealand populations of around 20 bird species present
- Significant areas of habitat exist for birds with restricted distributions
- Habitats for indigenous species that are migratory in New Zealand exist.

In addition the lake meets multiple criteria under the Ramsar Convention on Wetlands of International Importance. A summary of these and other forms of recognition are given in Te Rūnanga o Ngāi Tahu (2005: 69-71).

Underpinning these values is the diversity of different microhabitat types that provide a wide range of foraging and breeding opportunities (Figure 1). The list of indigenous species found on the lake, their guilds, conservation status and population characteristics, is provided in Appendix A (for information purposes Appendix B lists key exotic species). Figures 2-4 also demonstrate the typical annual cycles of use for some of the key species and groups of interest. While the data are dated (1980s), they

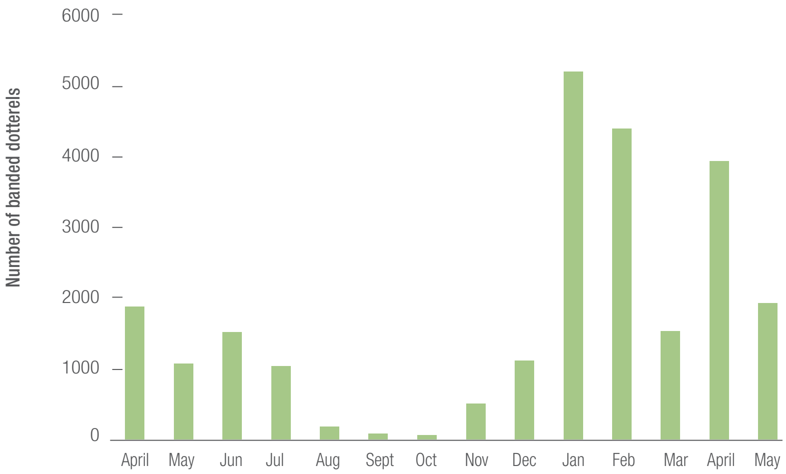

FIGURE 2. An annual cycle of banded dotterel at Te Waihora/Lake Ellesmere: 1986–87.

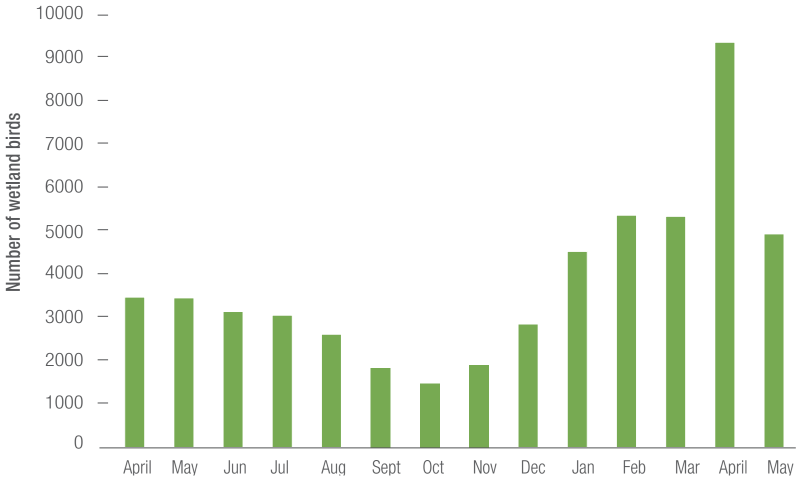

FIGURE 3. The total wetland bird cycle of numbers for Te Waihora/Lake Ellesmere: 1986–87.

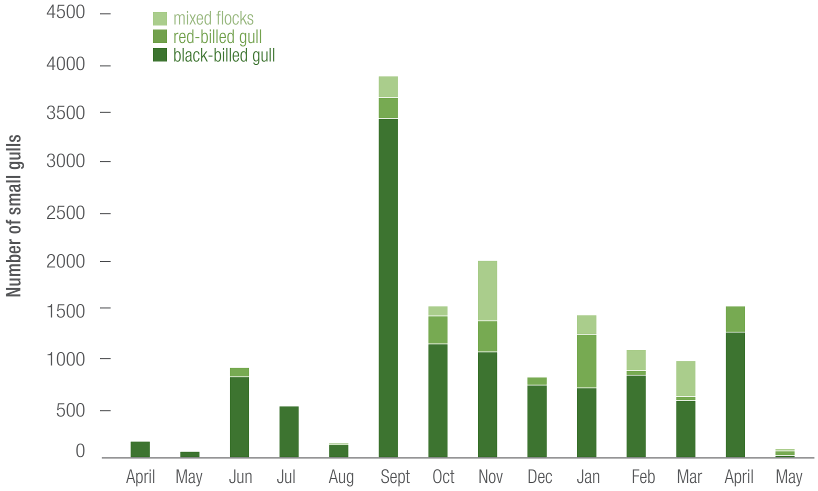

FIGURE 4. Annual cycle of 'small gull species' at Te Waihora/Lake Ellesmere: 1986–87.

Photo **Sharp-tailed Sandpiper - the lake is a New Zealand stronghold for this international migrant wader.** Photography **Colin Hill.**

do represent the most detailed monitoring effort ever undertaken for the lake, and are likely still relevant in terms of the cyclic patterns shown.

It is also very clear that the lake has high cultural and recreational values with respect to wildlife and that these have varied hugely over time, e.g., some bird species such as brown teal that were harvested by the Tangata Whenua in the past are now locally extinct, and while game bird shooting is very important so too now is bird watching. In relation to all of the above it is clear that a diverse range of habitats occur around the lake and these are strongly influenced by seasonal lake level management, by riparian management practices, and by other human induced pressures, e.g., mammalian predation.

Proposed desirable wildlife outcomes

Based on the above and discussions with 'key contacts' the following outcomes for wildlife are proposed for the lake:

- Species diversity should be maximised with a target average level of 50 indigenous species from seven guilds recorded per annum: composed of 40 'core' (those expected to occur at the lake on an annual basis) and 10 regular migrant or vagrant species (from guilds 1, 2, 3 or 6);
- Enhance populations of species whose total populations are at defined conservation risk (see Hitchmough *et al.* 2007) and which rely on the lake for critical life stage requirements, e.g., Australasian bittern, banded dotterel, Caspian tern and grey teal;
- Sustainably[3] manage harvestable species, e.g., black swan (including their eggs), Canada goose and mallard duck, while also managing for their interactions with other sensitive ecosystem components and socio-economic considerations (e.g., some species like Canada goose are both resource and pest);
- Provide the optimised range of habitat conditions to provide for all of the above, especially in terms of lake level management, water quality, and riparian management.

7.5 Indicators to measure the changing state of wildlife against the proposed desired outcomes

Much has been written about how to choose indicators of environmental change and in New Zealand there was a process led by Ministry for the Environment (MfE), the Environmental Performance Indicator programme, which attempted to define a core set of indicators for New Zealand - that process has had limited success. More recently, Hamill (2006) has reported a snapshot of lake water quality in New Zealand. Notably, while ecological condition trends were reported for key North Island lakes (e.g. Taupo), no similar information was reportable for Te Waihora/Lake Ellesmere. In addition, the Department of Conservation (DOC) has reviewed the need for indicators of 'ecological integrity' (Lee *et al.* 2005). DOC has developed a draft list of indicators that it is now beginning to assess in terms of their usefulness in the field.

There is no planning document that brings an integrated view of the overall state of a lake in terms of a broad range of interests. With respect to Te Waihora/Lake Ellesmere only Taylor (1996) presents an integrated report on the lake, albeit without the necessary outcome targets against

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[3] Including consideration of the potentially detrimental effects of some species if present in very large numbers, i.e., black swan and Canada goose.

which reporting should proceed. Given the above and the proposed outcomes for wildlife (section 3) it is now necessary to formulate indicators to help bridge this gap in knowledge about the lake. The following two sections identify indicator selection criteria and present a proposed set of indicators.

Key principles in indicator selection

Te Waihora/Lake Ellesmere is a complex system. In these sorts of systems linear causes and effects are atypical (see Hughey *et al.* 2009). Nevertheless managers and others require indicators that show changes to the state of the wildlife (and other values of importance).

Global Environment Forum projects and programmes, and many others as well, typically incorporate indicators chosen against SMART criteria[4]:

- **Specific:** Related to achieving a specific objective/outcome
- **Measurable:** ALL parties agree on the indicator, what it covers and there are practical ways of measuring the indicator and reporting the results
- **Achievable and Attributable:** There is a known cause and effect link so that if the indicator changes to an undesired level then an intervention can be undertaken
- **Relevant and Realistic:** ALL stakeholders must buy into the indicators
- **Time-bound,** timely, trackable and targeted.

An additional criterion, based on the integrated nature of this work, can be proposed:

- **Already in use for** related purposes, e.g., Fish and Game annually monitors Canada goose numbers and these same data can be used for a sustainable harvest indicator.

We now use these criteria as a basis for developing wildlife indicators for the lake.

The proposed indicators

Based on the SMART(A) criteria and the proposed outcomes the indicators suggested or appropriate for wild life of Te Waihora/Lake Ellesmere are shown in Table 1 and expanded on in Table 2.

7.6 The current state of wildlife of Te Waihora/Lake Ellesmere

The following outlines the state of the lake's wildlife and habitat using the indicators suggested above, and where possible an attempt is made to report trends against the following timeline:

- pre Maori (<1000AD)
- Maori (1000AD-1820)
- early European development of the lake and its environs (1820-1877)

TABLE 1. **Outcomes and indicators for wildlife.**

Proposed outcome	Suggested indicator (see also Table 2)	How measured
Species diversity should be maximised with a target average level of 50 indigenous species from 7 guilds recorded per annum. The 50 is further subdivided into: 40 'core' (those expected to occur at the lake on an annual basis) and 10 regular migrant or vagrant species (from guilds 1,2,3 or 6) – see Appendix A for the 'core' 40 list.	Maintenance or improvement of the representative range of indigenous species and guilds recorded at the lake	Number of guilds and number of indigenous species recorded annually
		Diversity of foraging guilds/yr
		Diversity of migrant waders/yr
		Percentage of species that are long-distance migrants
		Number of 40 'core' species recorded annually
Enhance the populations of **conservation and taonga** species whose total populations are at some defined conservation risk (see Hitchmough *et al*. 2007) and which rely on the lake for critical life stage requirements, e.g., Australasian bittern (matuku), banded dotterel, Caspian tern (tara) and grey teal (tete);	Trend in numbers of breeding pairs of Australasian bitterns	Frequency of occurrence of acutely and chronically threatened species/yr
	Trend in numbers of post-breeding banded dotterels	Annual index counts of bittern in breeding season
	Trend in numbers of breeding pairs of Caspian terns	February and June census of dotterels annually
	Trend in number of grey teal over-wintering	Annual count of Caspian terns in breeding season
		Annual census of grey teal in April
Sustainably manage[5] harvestable species, e.g., black swan (and their eggs), Canada goose and mallard duck;	Trend in black swan numbers	Annual census in June
	Trend in Canada goose numbers	
Provide the **optimised range of habitat conditions** to provide for all of the above, especially in terms of lake level management, water quality, and riparian management.	Trend in areas of habitat areas seen as critical to meet the needs of 1, 2 and 3 above	Critical habitats identified and mapped using remote sensing techniques as a baseline
	Increase in areas of priority habitat through restoration efforts	Remapping of critical habitats occurs at 5-yr intervals
	Maintenance of populations of species representative of each foraging guild present on the lake	Annual census of little shag (October breeding census), NZ shoveler, NZ scaup (April), pied stilt (February and June), banded dotterel, black swan (June), black-billed gull (June) and bittern (July)

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[4] See: http://gefweb.org/MonitoringandEvaluation/MEPoliciesProcedures/MEPIndicators/mepindicators.html accessed 8 Feb 2007

[5] Including consideration of the potentially detrimental effects of some species if present in very large numbers, i.e., black swan and Canada goose.

TABLE 2. **Bird populations of Te Waihora/Lake Ellesmere for seven guilds and key species therein to be used as indicators (modified and updated from Taylor (1996)).**

Guild	Key Species common name	Scientific name	Maori name	Justification	Relationship to other resources/ indicators
Open water divers	Little shag	*Phalacroxorax melanoleucos*	Kawaupaka	Representative of guild. Most numerous cormorant and local breeding species. Needs healthy small fish and crustacean populations for foraging. Requires fresh waters for feeding	Relies on fish for feeding
	NZ Scaup	*Aythya novaeseelandiae*	Papango		Diving feeder
Deep water waders	Pied stilt	*Himantopus leucocephalus*	Poaka	Representative of guild. Most numerous wader; needs extensive and healthy saltmarshes with variable water levels Taonga	Invertebrate feeder
	White heron	*Egretta alba*	Kotuku		Relies on fish for feeding
Shallow water waders	Banded dotterel	*Charadrius bicinctus bicinctus*	Tuturiwhatu	Representative of guild. Needs extensive and healthy saltmarshes that are frequently exposed and inundated	Invertebrate feeder
Dabbling waterfowl	Black swan	*Cygnus atratus*	Wani	Representative of guild. Cultural and recreational importance	Submerged microphyte feeder; recreation
	Canada goose	*Branta Canadensis*		Recreational importance	Recreation, farming
	NZ shoveler	*Anas rhynchotis*	Kuruwhengi Pateke	Representative of guild. Most important habitat in NZ. Requires brackish open waters for feeding. Recreational importance	Filter feeder
Aerial hunting gulls and terns	Black-billed gull	*Larus bulleri*	Tarapunga	Representative of guild. Endangered species.	Invertebrate feeder
	Caspian tern	*Sterna caspia*	Tarã nui	Threatened species breeding at lake	Fish feeder
Swamp specialists	Australasian bittern	*Botaurus stellaris poiciloptilus*	Matuku	Threatened species – one of largest populations on eastern SI. Representative of guild. Needs healthy small fish for foraging	Positive correlation with eel abundance (see Self 2005)

- European-driven lake opening regime (1877-1947)
- present day formal regime including the Wahine storm event, a major storm event that occurred into 1968 and was considered to have severely damaged the lake's weed beds.

Naturally, most of the evidence of trends in condition for the period prior to even as recently as the 1980s will be qualitative, to an extent anecdotal and in places highly speculative, but where possible based on known habitat condition and its relation to species presence, and to habitats and their use by wildlife, elsewhere. We know that pre Maori the lake was young and its associated wetlands were very large (2-3 times its current area). We can also surmise that wildlife was prolific, and likely highly diverse (see Holdaway *et al*. 2001). This is likely because habitats would have been dominated by largely open water and swamp edges, favouring the following guilds:

- Open water divers
- Deep water waders
- Dabbling waterfowl, including black swan
- Aerial hunting gulls and terns
- Swamp specialists
- Riparian wetland species.

It is possible that shallow water waders (high level of current species diversity) were few in number and diversity given likely lake conditions at the time (i.e., lack of extensive mud flat areas). On the other hand some species that became extinct in Maori (moa) and European (brown teal and fernbird) times would have been present in large numbers, therefore representing high levels of diversity.

Maori (1000AD-1820)

Maori were the first to undertake any management of lake openings, but at much higher levels than in 'modern' European times. As a consequence it is likely some of the geographical patterns of the lake changed substantially and led for example to formation of areas like the Greenpark Sands. Some species around the lake became extinct during this period (moa and black swan, plus other waterfowl?) but overall abundance and species diversity would

Contribution to trial national level indicators (see Lee *et al.* 2005)	Origin and breeding status at the lake	Typical numbers at one time (peak season)		Maximum percentage of national population using the lake per year (Appendix A)	
		1985-88	2006-07	1985-88	2007
5.1.2 Demography of widespread animal species 5.1.4 Representation of animal guilds	Native; Breeding	100-500	18	<1	<1
5.1.2 Demography of widespread animal species	Native; Breeding	10000	2937	33%	?
5.1.4 Representation of animal guilds;	Native	1-5	1-5	20%	15%
4.3.2 Security of chronically threatened taxa under active management;	Native; Breeding	1000+3000	1000-2000	10%	4%
5.1.2 Demography of widespread animal species	Native; Breeding	6000-13000	up to 10651	25%	?
8.1.3 Impacts on ecological integrity of land used for recreation	IIntroduced				
5.1.2 Demography of widespread animal species	Endemic; Breeding	500-15000	up to 3405	10%	2%
4.2.3 Security of acutely threatened taxa under active management	Endemic	500-3000	up to 1592	10%	3%
4.2.4 Demographic response to management for selected taxa	Native; Breeding	10-40	up to 63	2%	2%
4.2.3 Security of acutely threatened taxa under active management	Native; Breeding	20	n.c.	3-5%	unknown

have been very high, perhaps even higher than in pre Maori times, i.e., it might be postulated that the increase in habitat diversity with occasional lake openings would have increased species diversity at a rate greater than the number of local extinctions. Seven guilds would have been represented, all in high diversity and abundance. It is possible, however, that shallow water waders may have had only occasional use given the lake was opened very infrequently, i.e., it seems maybe on average around one opening every two-three years.

Early European development of the lake and its environs (1820-1877)

There are records that "the Maoris used to let the lake out every two or three years and since the arrival of the Canterbury Colonists they are known to have let it out in the years 1852, 1854, 1861, 1863, 1865 and 1867. In 1868 it was let out by Chapman and since then it has been let out every year by white man. The Maori interest in lake heights was due to lake water threatening the Taumutu Pa" (A report to the Canterbury provincial Government on the drainage of Lake Ellesmere by Mr W.B. Bray, April 1875) (Harris 1947, cited in Reid and Holmes 1996: 51). During this time period swamplands were beginning to be drained, introduced mammalian predation began, and recreational hunting would have pressured some bird species-in combination these activities would have threatened some species, e.g., brown teal. Overall then abundance and diversity would still have been high, indeed likely higher in terms of diversity of shallow water waders as annual conditions might have been more suitable for this guild.

European-driven lake opening regime (1877-1947)

Glennie and Taylor (1996) note that Selwyn County Council took the first steps in controlling lake levels in 1877 by letting tenders for the opening of the lake. While initial openings were based around ratepayer 'agitation' (Bowden *et al.* 1983; cited in Glennie and Taylor 1996: 10) they latterly developed into a pattern of summer 1.05 m and winter 1.13 m openings. Wildlife were abundant around the lake at this time as is evidenced

Photo **Black swan and cygnets is a very common native species of waterfowl.** Photography **Colin Hill.**

by recreational hunters and Maori taking a wide range of species, including both deep and shallow water wading birds. Wetlands were greatly drained over this period and several species became locally extinct, i.e., fernbird and brown teal. Others, including bittern, were likely hugely decreased in numbers. Overall though, abundance was high and diversity high.

Present day formal regime including the Wahine storm event

One single event, the 1968 Wahine storm, characterises the most significant changes to have occurred to the lake and its wildlife over this period (see Gerbeaux 1993). The storm destroyed the lake's weedbeds (although there is evidence they had been in declne for some time) and they have never recovered. As a result some aspects of water quality have changed, black swan numbers have declined, etc. Other habitat changes have occurred as a result of a more formal lake level management regime and the National Water Conservation Order-it is unknown how much either or both have influenced total species diversity, although the existence of a variable lake level management regime seems likely to enhance diversity.

The other major change in this period has been the growing interest in bird watching as a recreational activity which in Canterbury is heavily focused on the lake. One result of this interest has been the ever increasing number of 'new' species recorded on the lake, thus increasing recorded total diversity of the lake and its environs.

Specific changes in state related to the indicators in this period are:

- Since later Maori and certainly early European occupation an ongoing total increase in the **diversity** of species recorded at the lake with an underlying level of 'core' diversity that declined and now appears to be remaining static.

  Evidence:
  Based on reports over time the overall species list for the lake is increasing and the annual number of indigenous species presence is remaining static.
  Prognosis for this indicator:
  healthy

- Slow declines in some **conservation species which** are likely to mirror national level declines, e.g., Bittern and Caspian tern.

  Evidence:
  All New Zealand tern species in New Zealand are in decline. The extent to which Te Waihora/Lake Ellesmere is contributing to, or reflecting this decline is unknown. It is also likely that conditions are worsening for bittern, and numbers may be in decline, but there is insufficient monitoring to determine.
  Prognosis for this indicator:
  Static to unhealthy

- In terms of **sustainable harvest species** there was a rapid decline in black swan in the 1960s and 1970s and a fluctuating above target number of Canada geese until recent times (Figures 5 and 6). The lake should be supporting more swans, and geese should be under the target level.

  Evidence:
  There are considerable data for swans and geese. Estimated swan numbers around the time of the Wahine storm are 70000, now around 4000.
  Prognosis for this indicator:
  unhealthy

- **Habitat availability** and quality varies greatly and is poorly managed, e.g., willow growth in Harts Creek might be negatively influencing bittern numbers, long periods of low lake levels (summer of 05-06) disastrous for many species as essential riparian habitats become dessicated. There is anecdotal evidence that these trends may be worsening.

  Evidence:
  Although monitoring of, for example, bitterns is not occurring we know they require large areas of habitat, but that the area of suitable habitat is declining (Grove and Pompei 2008). Records of lake level opening periods show the

extended low lake levels in the 05-06 opening, which were likely to have adverse impacts of swampbird habitat.

Prognosis for this indicator:
Static to unhealthy

A summary of the present day trends is given in Table 3. Only one indicator is healthy, i.e., diversity - this indicator is probably remaining this way because habitat diversity is being maintained (albeit with some declines in quality) and the indicator is not dependent on population size criteria. The status of some conservation and taonga species is clearly likely in decline as habitat conditions deteriorate, e.g., willow invasion is likely reducing habitat for bittern at Harts Creek, while declines of other genera, e.g., terns, is a nation-wide phenomenon. Sustainable harvest species present a 'mixed bag'. From 2000 to 2005 Canada geese numbers were maintained below target levels with only 2006 in recent years being negative. Conversely, black swan numbers are well below likely desirable levels, probably as a result of the loss of the weed beds before, during and after the 1968 Wahine storm. As noted already there is deterioration of habitat occurring in Harts Creek and other areas as a result of willow invasion. Poorly controlled grazing, inappropriate lake level management and other human-induced influences are contributing to an ongoing net decline in habitat condition. Overall then while wildlife values are clearly high there is cause for concern with several key indicators in decline.

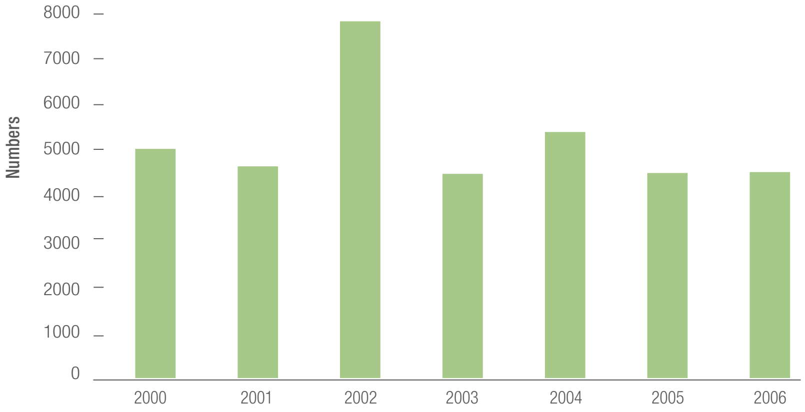

FIGURE 5. Black swan trend counts for Te Waihora/Lake Ellesmere (June aerial surveys) (Source: B. Ross, Fish and Game, 2007, draft report).

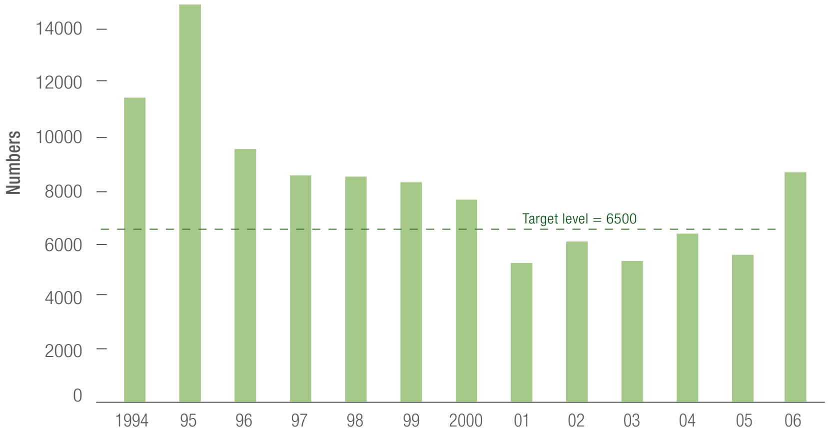

FIGURE 6. Canada goose trend counts for Te Waihora/Lake Ellesmere (June aerial surveys)(Adapted from Ross, 2007, draft report). Note the target level represents the maximum number for the lake under the Canada goose management plan (see Fish and Game 2000).

TABLE 3. **Summary of wildlife state and indicator trends for Te Waihora/Lake Ellesmere.**

Indicator	State	Trend
Diversity	Healthy	Stable
Conservation and taonga species status	Static to unhealthy	Declining
Sustainable harvest species	Unhealthy	Stable
Habitat availability	Static to unhealthy	Declining

7.7 The relationship of indicator change to lake level and other human-related drivers of change

Water level management

There is no one lake level management regime that if implemented would benefit all wildlife on Te Waihora/Lake Ellesmere-and, there has never been one. Rather, different regimes will suit different guilds of birds in different ways, sometimes at the expense of other guilds. These effects are most obviously related to the lake level management regime. Thus, recommending a lake level management regime for wildlife is about maximising average benefits to desirable wildlife, e.g., a more-or-less permanently high lake level would benefit many guilds but effectively destroy the exposed mud and turfland flats exploited by the deep and shallow water waders. Table 4 gives an indication of the extremes of these regimes. An optimum (implying the obvious tradeoffs are considered and balanced by conservation managers) water regime will ensure that there is sufficient open water for species that prefer that zone, but will also ensure a general lowering of levels in spring so that saltmarshes become exposed and wind action ensures regular temporary re-watering of some of those saltmarshes and also some of the swampland areas.

Grazing

Grazing destroys swamp and saltmarsh vegetation and stock can trample or disturb nesting birds. Grazing needs to be managed in some habitats and excluded from others. Grazing in key habitats at key times, e.g., swan nesting along the shore of Kaitorete Spit or wet saltmarshes, should be avoided.

Eutrophication

Impacts are largely unknown for the wildlife although if water quality degrades to a 'tipping point' level where there is a significant reduction in invertebrate food production, the impacts could be catastrophic. There is insufficient information to enable an informed evaluation of the current situation or trends.

Recreation

As a general rule recreational vehicles should be prohibited from venturing into key habitats where they can destroy habitat and disturb wildlife. Exceptions for essential works and for managed tourism and recreation may be possible.

Weeds, e.g., grey willow

The proliferation of grey willow in Harts Creek needs to be reversed as it will likely lead to a long term reduction in bittern and other bird and fish habitat.

Predation

Mammalian predators are likely abundant around the lake. No research has been undertaken into their significance; however, introduced predators cause significant impacts on indigenous birds in all habitat types studied to date in New Zealand (see Dowding and Murphy 2001). The suite of predators present is typical of that in coastal areas and braided rivers, where impacts are catastrophic. Some predator management is desirable and potentially could follow designs currently being implemented in the Whangamarino and Awarua Plains wetlands

7.8 Identification of management interventions

The state of Te Waihora's wildlife is mixed, although overall only species diversity is considered healthy with the other indica-

TABLE 4. **Generalised relationships between wildlife guilds and variation in lake level.**

Guild	Example Species (common name)	Lake level regime that would most benefit this guild	Lake level regime that would be most harmful to this guild
Open water divers	Little shag	High lake permanently	Low lake level permanently
Deep water waders	Pied stilt	Seasonally adjusted levels including moderate to low levels in spring and autumn	High lake permanently
Shallow water waders	Banded dotterel	Seasonally adjusted levels including moderate to low levels in spring and autumn	High lake permanently
Dabbling waterfowl	Black swan	High lake permanently	Low lake level permanently
	Canada goose	High lake permanently	Low lake level permanently
Aerial hunting gulls and terns	Black-billed gull	High lake permanently	Low lake level permanently
Swamp specialists	Australasian bittern	High lake permanently	Low lake level permanently
Riparian wetland species	Kingfisher	High lake permanently	Low lake level permanently

TABLE 5. **Proposed outcomes and suggested management actions for wildlife of Te Waihora/Lake Ellesmere.**

Proposed outcome	Suggested management actions related to indicator trend
Species diversity should be maximised with a target average level of 50 s pecies (40 of which are 'core') from 7 guilds recorded per annum;	Implement the lake closing regime as per the Water Conservation Order, but subject to key management and ecological criteria
	Implement specific management techniques outlined below.
Enhance the populations of **conservation and taonga species** whose total populations are at some defined conservation risk (see Hitchmough *et al.* 2007) and which rely on the lake for critical life stage requirements, e.g., Australasian bittern, banded dotterel, Caspian tern and grey teal;	Key conservation species management areas to be identified, e.g., Harts Creek and Kaituna Lagoon for bittern, Greenpark Sands for banded dotterels and other waders;
	Active management for conservation species be undertaken in these key management areas, e.g., willow control and water level management in Harts Creek and Kaituna lagoon.
	General predator control.
	No further loss of emergent 3-tier swamp vegetation, and restoration at key sites, particularly along the western shores of the lake.
Sustainably[6] manage harvestable species, e.g., black swan, Canada goose and mallard duck;	Reduce Canada goose numbers to meet CG management plan requirements;
	Explore the potential to re-establish brown teal, ultimately for cultural harvest?
Provide the **optimised range of habitat conditions** to provide for all of the above, especially in terms of lake level management, water quality, and riparian management.	Map extent of microhabitat types using remote sensing and ground truthing.
	Maintain the extent of key microhabitats through active wetland management and statutory and non-statutory advocacy and education.
	Implement the lake closing regime as per the Water Conservation Order.
	Manage grazing regimes along shoreline habitats.
	Manage recreational activities that may degrade habitats.

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[6] Including consideration of the potentially detrimental effects of some species if present in very large numbers, i.e., black swan and Canada goose.

tors ranging from static to unhealthy. Given this state what management actions could be undertaken to improve the situation (see Table 5)?

7.9 Discussion and conclusions

Te Waihora/Lake Ellesmere, despite all the largely detrimental changes over the last 100 or so years, remains a wetland of national and international importance for wildlife-specifically it contains very large numbers of birds representing a wide range of guilds and species living in a wide range of habitats. Despite these levels of importance some habitats associated with the lake are declining in value and so too are the species and guilds linked to these habitats. Overall then while the state of wildlife can be considered in 'reasonable health', the trend is probably a slow decline in value for wildlife. To reverse this trend, and secure the 'health' of the lake's wildlife, a range of management actions needs to be taken. These actions range from immediate work on willow control to improvements in lake level (linked to the water conservation order provisions) and riparian management-some of these are urgent, some are more strategic, but all are necessary.

7.10 Acknowledgements

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7.12 Appendices

Appendix A

Indigenous bird species, guilds and estimated population sizes for all species recorded at Te Waihora/Lake Ellesmere from c.1900–present.

Nomenclature from Heather and Roberston (1996)

The list includes species that use the lake and its wetland margins. It excludes oceanic species and vagrants that occur at sea off the Kaitorete Spit, penguins that may moult along the Kaitorete Spit, introduced species, and extinct species.

Key	
B	**Breeding** species,
F	Uses the lake for **feeding** only,
M	Regular international **migrants** that occur most years,
V	Vagrants, i.e., species that occur only **very rarel**y on the lake
X	Locally **extinct** post European arrival (but still occur elsewhere in New Zealand)
Outlined rows	The '**core' 40 species** for monitoring species diversity on an annual basis

Species common name, by guild	Maori name	Scientific name	Origin and breeding status	New Zealand wide conservation status - 2007
1. Open water divers				
Australasian crested grebe	Puteketeke	*Podiceps cristatus*	B	Acutely threatened
NZ dabchick	Weweia	*Poliocephalus rufopectus*	X	Chronically threatened
Australasian gannet	Takapu	*Morus serrator*	V	
Australian pelican		*Pelecanus conspicillatus*	V	
Black shag	Kawau	*Phalacrocorax carbo*	B	Chronically threatened
Little shag	Kawaupaka	*P. melanoleucos*	B	
Pied shag	Karuhiruhi	*P. varius*	F	
Little black shag		*P. sulcirostris*	V	Chronically threatened
Spotted shag	Parekareka	*Stictocarbo puncatatus*	F	
NZ scaup	Papango	*Aythya novaeseelandiae*	B	
Australian coot		*Fulica atra*	V	
White-eyed duck		*A. australis*	V	
2. Deep water waders				
White heron	Kotuku	*Egretta alba*	F	Acutely threatened
Intermediate egret		*E. intermedia*	V	
Little egret		*E. garzetta*	M	
Reef heron	Matuku moana	*E. sacra*	V	Acutely threatened
White-faced heron		*Ardea novaehollandiae*	B	
Royal spoonbill	Kotuku ngutu-papa	*Platalea regia*	F	
Nankeen night heron		*Nycticorax caledonicus*	V	
Glossy ibis		*Plgadis falcinellus*	M	
Australian white ibis		*Threskiornis molucca*	V	
Finsch's oystercatcher[9]	Torea	*Haematopus finschi*	F	
Variable oystercatcher	Toreapango	*H. unicolor*	F	
Pied stilt	Poaka	*Himantopus himantopus*	B	
Black stilt	Kaki	*Himantopus novaezelandiae*	B	Acutely threatened
Australian red-necked avocet		*Recurvirostra novaehollandiae*	V	
Banded stilt[10]		*Cladoryhnchus leucocephalus*	V	

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[9] Also referred to as South Island pied oystercatcher (SIPO).

[10] Although not formerly recognised on the New Zealand bird species list, there is a specimen from Lake Ellesmere in the Canterbury Museum (Tunniclife 1977), and Cayley (1961) cites this species as straggling to New Zealand.

Photo **The Pied Stilt is a very common sight around the lake.** Photography left **Shutterstock** right **Colin Hill.**

Typical numbers at one time 1985 and 1988[11],[12]	Typical numbers at one time 2000-2007	Max at one time (1980-present)	National population (year estimated in) and approx. proportion of national total present at lake at one time (%)[13]
0-1	10-20	32	400 (2004) (8%)
-	-	-	
0	0	1	
0	0	1	
100-200	250	500	5-10000 pairs (3%)
400-500	500	500	5-10000 pairs (5%)
0	10-20	24	5-10000 pairs (<1%)
0	0	6	
1-100	<200	20	10-50000 pairs (<1%)
0	100-200	235	20000 (1990s) (<1%)
0	0	3	
0	0	0	
1-15	1-15	19	100-120 (2000) (19%)
0	0	1	
0-1	0-1	2	<50 (4%)
0	0	0	
100-200	100-200	421	Widespread & common
0-2	70-120	199	610 (1995) (30%)
0	0	0	
0	0	2	Frequent vagrants
0	0	0	
80	20-75	143	85000 (1995) (<1%)
0	<5	4	
1000-3000	Up to 2937	10000	30000 (1993) (33%)
1-4	2	4	89 (2007) (4%)
0	0	0	
0	0	0	

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[11] Bird data for this period was collated from O'Donnell (1985) and NWASCA (1988), as reported in Taylor (1996: 191).

[12] Data from DoC unpubl reports, Ornithological Society of NZ unpubl. reports and A. Crossland, Christchurch City Council, from the February 2006 survey, and from the February 2007 survey.

[13] Data from Heather and Robertson (1996) unless otherwise noted.

Species common name, by guild	Maori name	Scientific name	Origin and breeding status	New Zealand wide conservation status - 2007
Eastern curlew		*Numenius madagascariensis*	V	
Whimbrel		*N. phaeopus*	V	
Bar-tailed godwit	Kuaka	*Limosa lapponica*	M	
Black-tailed godwit		*Limosa limosa*	V	
Hudsonian godwit		*L. haemastica*	V	
Siberian tattler		*Tringa brevipes*	V	
Greenshank		*T. nebularia*	V	
Lesser yellowlegs		*T. flavipes*	V	
Marsh sandpiper		*Tringa stagnatilis*	V	
Stilt sandpiper		*Micropalama himantipus*	V	
3. Shallow water waders				
NZ dotterel	Tuturiwhatu	*Charadrius obscurus*	V	Acutely threatened
Banded dotterel	Tuturiwhatu	*C. bicinctus*	E, B	Chronically threatened
Red-capped dotterel		*C. ruficapillus*	V	
Black-fronted dotterel		*C. melanops*	F	
Large sand dotterel		*C. leschenaultii*	V	
Mongolian dotterel		*C. mongololus*	V	
Oriental dotterel		*C. veredus*	V	
Wrybill	Ngutu parore	*Anarhynchus frontalis*	F	Acutely threatened
Pacific golden plover		*Pluvialis fulva*	M	
Spur-winged plover		*Vanellus miles*	B	
Turnstone		*Arenaria interpres*	M	
Lesser knot	Huahou	*Calidris canutus*	M	
Great knot		*C. tenuirostris*	V	
Sanderling		*C. alba*	V	
Curlew sandpiper		*C. ferruginea*	M	
Sharp-tailed sandpiper		*C. acuminata*	M	
Pectoral sandpiper		*C. melanotos*	M	
Red-necked stint		*C. ruficollis*	M	
Little stint		*Calidris minuta*	V	
Long-toed stint		*C. subminuta*	V	
Broad-billed sandpiper		*Limicola falcinellus*	V	
Ruff (Reeve)		*Philomachus pugnx*	V	
Little whimbrel		*Numeniusminutus*	V	
Terek sandpiper		*Tringa terek*	V	
Grey phalarope		*Phalaropus fulicarius*	V	
Red-necked phalarope		*Phalaropus lobatus*	V	
Wilson's phalarope		*Phalaropus tricolor*	V	
4. Dabbling waterfowl				
Black swan[14]	Wani	*Cygnus atratus*	B	
Cape Barren goose*		*Cereopsis novaehallandiae*	V	
Paradise shelduck	Putangitangi	*Tadorna variegata*	B	
Chesnut-breasted shelduck		*T. tadornoides*	V	
Grey duck	Parera	*Anus superciliosa*	B	Acutely threatened
Australasian shoveler	Kuruwhengi, Pateke	*A. rhynchotis*	B	
Brown teal	Pateke	*A. aucklandica*	X	Acutely threatened
Grey teal	Tete	*A. gracilis*	B	
Mixed shoveler/ teal				

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[14] Black swans and Cape Barren geese are generally considered introduced species. However, Worthy (1998) found that bones of the 'extinct' New Zealand swan were identical to those of the introduced Australian species. The 'New Zealand goose' is in a similar position with the Cape Barren goose. Thus, it appears that these species are indigenous species that were inadvertently re-introduced to New Zealand.

Typical numbers at one time 1985 and 1988[11],[12]	Typical numbers at one time 2000-2007	Max at one time (1980-present)	National population (year estimated in) and approx. proportion of national total present at lake at one time (%)[13]
0	0	1	
0	0	0	
0-50	20-80	325	85-105000 (1995) (<1%)
0	0	13	
0	0	1	
0	0	1	
0	0	1	
0	0	0	
0	0	2	
0	0	1	
0	0	0	
1000-3000	1000-2000	4846	50000 (1995) (10%)
0	0	0	
0	0	2	
0	0	1	
0	0	1	
0	0	1	
50-200	50-200	459	4500 (2004) (10%)
50-70	122	122	600-1200 (1995) (10-20%)
100-500	100-200	1052	Abundant & widespread
0-10	0-10	34	5-7000 (1995) (<1%)
5-90	10-35	85	50-70000 (1995) (<1%)
0	0	1	
0	0	3	
5-70	10-20	86	50-150 (1995) (60%)
10-25	10-25	33	50-200 (1995) (17%)
1-3	0-6	10	<20 (1995) (50%)
200	Up to 63	220	150-300 (1995) (70%)
0	0	1	
0	0	1	
0	0	1	
0	0	2	
0	0	2	
0	0	4	
0	0	1	
0	0	0	
0	0	2	
6000-13000	Up to 10651	16000	63000 (1980) (25%)
0	2	2	
10-400	100-500	1635	120000 (1981) (1%)
0	2	2	13 (2007) (15%)
<100	?	?	<500000 (1995)
500-15000	Up to 3405	>15379	150000 (1980s) (10%)
-	-	-	
500-7000	Up to 10979	10979	>50000 (1995) (22%)
5000-10000	Up to 1260	27166	

Species common name, by guild	Maori name	Scientific name	Origin and breeding status	New Zealand wide conservation status - 2007
5. Torrent specialists				
None present				
6. Aerial hunting gulls & terns				
Brown skua	Hakoakoa	*Catharacta skua*	V	Acutely threatened
Antarctic skua		*C. maccormicki*	V	
Arctic skua		*Stercorarius parasiticus*	M	
Pomarine skua		*S. pomarinus*	M	
Black-billed gull		*Larus bulleri*	F	Acutely threatened
Red-billed gull	Tarapunga	*L. scopulinus*	F	Chronically threatened
Black-backed gull	Karoro	*L. dominicanus*	B	
Caspian tern	Taranui	*Sterna caspia*	B	Acutely threatened
White-fronted tern	Tara	*S. striata*	F	Chronically threatened
Black-fronted tern	Tarapiroe	*S. albostriatus*	F	Acutely threatened
White-winged black tern		*Chlidonias leucopterus*	M	
Arctic tern		*S. paradisaea*	V	
Fairy tern		*S. nereis*	X	Acutely threatened
Little tern		*Sterna albifrons*	M	
7. Swamp specialists				
Banded rail	Moho-pereru	*Rallus philippensis*	X	Chronically threatened
Spotless crake	Puweto	*Porzana tabuensis*	B	Chronically threatened
Marsh crake	Koitareke	*Porzana pusilla*	B	Chronically threatened
Pukeko	Pukeko	*Porphyrio porphyrio*	B	
Australasian bittern	Matuku	*Botaurus poiciloptilus*	B	Acutely threatened
Painted snipe		*Rostratula benghalensis*	V	
Japanese snipe		*Gallinago hardwickii*	V	
Fernbird	Matata	*Bowdleria punctata*	X	Chronically threatened
8. Riparian wetland species				
Kingfisher	Kotare	*Halcyon sancta*	B	
Welcome swallow		*Hirundo tahitica*	B	
Cattle egret		*Bubulcus ibis*	M	
Australasian harrier hawk	Kahu	*Circus approximans*	B	
NZ falcon	Karera	*Falco noveseelandiae*	V	Chronically threatened
Weka	Weka	*Gallirallus australis*	X	
NZ pigeon	Kereru	*Hemiphaga novaeseelandiae*	F	
Kea	Kea	*Nestor notabilis*	V	Acutely threatened
Shining cuckoo	Pipiwharauroa	*Chalcites lucidus*	F	
Long-tailed cuckoo	Koekoea	*Eudynamys taitensis*	V	
Black-faced cuckoo shrike		*Coracina novaehollandiae*	V	
Silvereye	Tauhou	*Zosterops lateralis*	B	
Grey warbler	Riroriro	*Gerygone igata*	F	
NZ pipit	Pihoihoi	*Anthus novaeseelandiae*	B	
Fantail	Piwakawaka	*Rhipidura fuliginosa*	F	
Bellbird	Korimako	*Anthornis melanura*	F	

Appendix B

Introduced species of importance at Te Waihora/Lake Ellesmere.

Dabbling waterfowl				
Mute swan		*Cygnus olor*	I, B	Protected
Canada goose		*Branta canadensis*	I	Game bird
Mallard duck		*Anas platyrhynchos*	I, B	Game bird

Typical numbers at one time 1985 and 1988[11],[12]	Typical numbers at one time 2000-2007	Max at one time (1980-present)	National population (year estimated in) and approx. proportion of national total present at lake at one time (%)[13]
0	0	1	
0	0	0	
0	0	6	
0	0	2	
500-3000	Up to 1592	5000	<50000 (2007) (10%)
10-500	Up to 59	544	100000+ (2000) (<1%)
500-1000	Up to 648	1561	Abundant & widespread
10-40	Up to 63	70	3000 (1995) (2%)
0-100	Up to 169	204	30000 (2000) (<1%)
0-50	54	58	5000 (1995) (1%)
0	0	4	<10 (1995) (40%)
0	0	1	
-	-	-	
0-1	0	11	
-	-	-	
?	n.c.	5	?
?	n.c.	26	?
250-500	Up to 28	502	Abundant
20	n.c.	20	580-725 (3-5%)
0	0	1	
0	0	1	
-	-	-	
10-50	n.c.	20	
100+	n.c.	514	
10-30	<10	94	<1000(10%)
?	58+	58+	Widespread & common
0	0	1	
-	-	-	
0	0	1	
0	0	1	
?	?	?	
0	0	1	
0	0	0	
?	?	?	
?	?	?	
?	?	?	
?	?	?	
?	?	?	

			National population and % of 2007 popn using the lake per year
40-50	10-20		100 (1990s) (50%)
7000-16000	6000-8000		50000 (30%)
500-9000	Up to 1388		3 million (1995)

COLIN HILL

08

CULTURAL HEALTH of the lake

CRAIG PAULING Te Rūnanga o Ngāi Tahu **JASON ARNOLD** Te Rūnanga o Ngāi Tahu

KO NGĀ HAU KI ĒTAHI WĀHI, KO NGĀ KAI KI ORARIKI
No matter which way the wind blows, there is always food at Orariki.
This whakatuaki refers to the year round abundance of food that was available at Orariki, the pā of Te Ruahikihiki, near Taumutu.
There was mahinga kai in all seasons, in all weather.

The State of the Takiwā tool developed by Te Rūnanga o Ngāi Tahu was used to assess the cultural health of Te Waihora in April 2007. Its development arose as the result of an agreement by Environment Canterbury to undertake a range of research programmes, including a Cultural Health Assessment, as a condition of the consent to open the lake. In parallel a Te Waihora specific cultural health tool is being developed through a joint Ngāi Tahu-NIWA-Health Research Council funded project that will provide a more comprehensive tool and provide a more complete cultural health assessment which the Takiwā tool cannot currently provide for this environment. The preliminary findings from the Takiwā based assessments, showed that the lake, and in particular the lake edge, still holds significant mahinga kai values, despite obvious water quality, modification, pressure and native vegetation issues. It also showed that although the lake edge received a moderate assessment, water and native fish values were not able to be directly assessed due to a limitation with the Takiwā method. Therefore, the development of a specific lake cultural health tool by Ngāi Tahu and NIWA will be important to gain a more accurate picture of the cultural health of the lake and the lake edge into the future.

8.1 Te Kōrero Whakataki
Introduction

While there is much 'western' science based research and monitoring reported for Te Waihora there is little of what can be described as reflecting a cultural health assessment. Cultural health information for Te Waihora is important considering the significance of the lake to Ngāi Tahu history, identity and ongoing wellbeing, and in particular due to the return of the lakebed to Ngāi Tahu as part of the Ngāi Tahu Claims Settlement Act 1998, as well as the joint management of the lake bed and surrounding conservation lands under the Te Waihora Joint Management Plan.

This chapter outlines the development of a cultural health monitoring tool for Te Waihora, and the results of a preliminary study using the Takiwā tool to monitor its core methods, some results from application to the lake, and related conclusions and recommendations. This chapter is based on two projects. The first involves the development of the Takiwā tool by Te Rūnanga o Ngāi Tahu, supported by the Ministry for the Environment, and its use to monitor the impacts of the lake opening consent held by Environment Canterbury, who also contributed to the development of the tool. The second project is the joint Ngāi Tahu/NIWA project to develop a specific cultural health tool for Te Waihora supported by the Te Waihora Management Board and funded by the Health Research Council.

8.2 Tāhuhu Kōrero
Background

State of the Takiwā is an environmental monitoring approach developed by Te Rūnanga o Ngāi Tahu as part of their Ki Uta Ki Tai—Mountains to the Sea Natural Resource Management framework (Pauling 2003) and outlined in the tribal vision, Ngāi Tahu 2025 (Te Rūnanga o Ngāi Tahu 2001). Its development has been partly funded by the Ministry for the Environment (MfE) and supported by Environmental Science and Research, Manaaki Whenua Landcare Research, NIWA, Envirolink Southern Community Laboratories, Environment Southland and Environment Canterbury.

The major objective behind State of the Takiwā is to ensure that tāngata whenua can build robust and defensible information on the health of the environment. This information can in turn be used to assess the effectiveness of both internal policy and practices as well as those of external agencies, including local councils which have statutory responsibilities to undertake monitoring and report on the state of the environment (Pauling 2004).

Currently, the State of the Takiwā approach incorporates a specially designed Access database and associated monitoring forms, developed to allow tangata whenua to capture, store, analyse and report their impressions of site quality gathered in a systematic manner over time. Overall the approach provides for recognition and incorporation of Māori values in relation to environmental management. It also links with the MfE Environmental Performance Indicator (EPI) programme, and with the Cultural Health Index (CHI) for rivers and streams (developed by Gail Tipa and Laurel Tierney). The Takiwā tool therefore provides a diagnostic tool for identifying issues (and sites) of concern to iwi and allows for remedial action to be prioritised, implemented and monitored for performance over time.

While it is being used as a 'one stop monitoring shop' by the iwi, it has been driven by concerns around water quality, and has been focused around assessing the health of rivers and streams. It is therefore limited in its application for monitoring species health and in assessing the health of other ecosystems including lakes, and requires further development of specific tools that can be added to the overall system. The joint Ngāi Tahu/NIWA project funded by the Health Research Council offers an opportunity to develop such a tool. The Te Waihora Cultural Health Study being undertaken within this project is therefore attempting to develop a tool that will provide for a more comprehensive assessment of Te Waihora. Unique themes and indicators developed through the Te Waihora Cultural Health Study will be incorporated into the State of The Takiwā database system enabling easy access and reporting.

8.3 Ngā Kauneke
Methods

Takiwā Site Assessments

State of the Takiwā data are captured and inputted from monitoring forms completed in the field for particular sites and visits. The system also allows for the collection and storage of historical information as well as photos, pictures or graphs about a site. Recent developments allow for data to be inputted onsite using electronic forms on a Panasonic Toughbook PC that eliminates 'double handling' of data.

Index/scoring calculations are included to grade and compare sites including the general Takiwā site health assessment, native species abundance, as well as the Cultural Health Index for Rivers and Streams, and the Stream Health Monitoring and Assessment Kit (SHMAK) for stream health at a site. An integrated reporting function allows users to print a range of reports on the data collected. It is envisioned that the upcoming Te Waihora tool will be simply incorporated into the electronic Takiwā database as a separate tab, in the same way as the CHI and SHMAK are currently.

Takiwā Monitoring Forms

These are aimed at recording observations and assessments by tangata whenua for a particular site using three main forms:

Site Definition

- Names, Site location, legal protection, special features, heritage/site significance, traditional species, etc.

Visit Details

- Date, time, weather conditions as well as prompts to ensure photographic references are taken

Assessment Questionnaire

- Overall health/state of a site
- Levels of modification/change at a site
- Suitability of the site for harvesting mahinga kai

- Access issues in relation to the site
- Amount of pressure from external factors
- Presence, abundance and diversity counts for taonga (valued) bird, plant and fish species, and other culturally significant resources as well as pest and weed species
- Willingness to return to the site for harvesting mahinga kai.

Te Waihora Cultural Health Assessment

The cultural health assessment undertaken in this study was done as a condition of the Te Waihora/Lake Ellesmere Lake Opening Consent obtained by Environment Canterbury. David O'Connell and Craig Pauling developed the initial brief and selected sites in liaison with David Aires (Environment Canterbury). Jason Arnold and Craig Pauling then developed a work plan and submitted it to Environment Canterbury for review.

The work plan outlined the following types of assessment:

- Takiwā
- CHI
- SHMAK
- *E. coli* assessments
- Electric fishing where appropriate.

Fourteen sites around the edge of lake were chosen, including seven associated with lake tributaries. A data collection hīkoi occurred over 11–12 April 2007; a report on the findings was submitted to Environmental Canterbury and presented at the 2007 Living Lake Symposium. Ultimately all this effort is assisting in development of a Cultural Health Tool for Te Waihora which will be the final tool of choice as it provides a fuller assessment of the cultural health of Te Waihora.

Ngā Kaimahi me ngā Kaiawhina
People involved

Those involved were:
Fieldwork: Lisa Smith (Ngāi Te Ruahikihiki), David O'Connell (Ngāi Te Ruahikihiki), Craig Pauling (Ngāi Te Ruahikihiki), Jason Arnold (WaihoraCoordinator), Dave Aires (ECan), Leigh Skerten (ECan)
Lab Work/*E. coli*:
John Aitken (Envirolink Labs) processed the *E. coli* samples.

Wāhi Whakamātau Monitoring Sites **(see Figure 1):**

1. Irwell River mouth, Irwell
2. Boggy Creek mouth, Irwell
3. Harts Creek mouth, Lakeside
4. Pakoau, Johnsons Road, Lakeside
5. Water Tower, Taumutu Commonage, Taumutu
6. Fishermans Point (overlooking Te Koru and Lake Opening), Taumutu
7. West end of Te Koru, Taumutu
8. Lower Selwyn Huts
9. North Greenpark Sands, off Wolfes Road
10. Mid Greenpark Sands, off Clarkes Road
11. Mouth Halswell River, Greenpark
12. Kaituna
13. Te Waiomakua Mahinga Kai Site, Kaitorete Spit
14. Harakeke (Flax) Swamp, Lower Kaitorete Spit

FIGURE 1. Location of the State of the Takiwā monitoring sites. Base Map sourced from ECan.

8.4 **Te Waihora** Cultural Health Study **Ngāi Tahu** NIWA Process

The first part of the process concerned tool development and trialling. Specifically it involved the following steps:

- Key participants identified and interviewed
- Analyse interviews and draft report
- Identify indicator themes, sites and mahinga kai to be measured
- Hui to develop draft tool
- Test the draft tool at 3-4 sample sites;
- Currently development is at this stage of the process
- Work with local tangata whenua to develop further indicators and assessment methods for monitoring individual mahinga kai species, including Tuna,

Pātiki, Harakeke and Kakī Anau (see Appendix A)

- Statistically correlate assessments to refine key indicators
- Finalise tool
- Assess remaining sites using final tool.

8.5 **Ngā Hua** Results

Takiwā Cultural Health Assessment

Based on the baseline data collected using the Takiwā tool the Te Waihora/Lake Ellesmere lake edge was found to be in a state of moderate cultural health (Table 1 summarises the data collected for the best and worst sites):

- 72% of sites were found to be of moderate health
- 21% rated as good
- 7% being rated as poor.

Overall, the sites scored well on willingness to harvest mahinga kai and access indicators but poorly on pressure, modification, and native species abundance indicators, particularly in relation to native vegetation dominance. Kaitorete Spit sites (Te Waiomakua and Harakeke Wetland) were the highest ranking sites (Figure 2), while Pakoau followed by the Kaituna River Mouth Site were the lowest scoring. Because the method was not specifically designed for

Photo **Kaitorete Spit sites 13 - Te Waiomakua mahinga kai site and 14 – Harakeke (Flax) Swamp, ranked the highest in terms of their cultural health representing two of the most 'intact' sites around Te Waihora.** Photography **David Aires.**

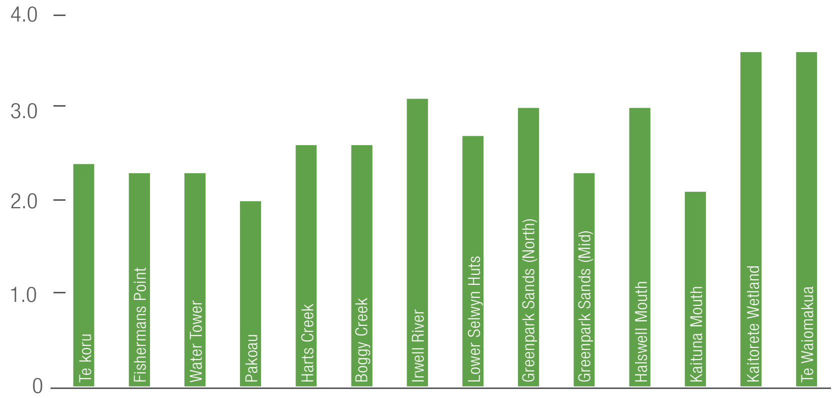

FIGURE 2. Takiwā Cultural Health Scores for 14 sites at Te Waihora/Lake Ellesmere–2007.

TABLE 1. **Comparison of the best and worst cultural health monitoring sites at Te Waihora.**

Criteria	Specific criteria	Te Waiomākua	Pākoau
Takiwā Assessment	Pressure	4	2
	Degree of modification	3	2
	Access for harvesting	5	2
	Willingness to harvest	5	3
	Would you return?	Yes	Yes
Overall health		4	1
Birds		Kāhu >	Karoro > Matuku > Papango
Plants		Reeds > > Ribbonwood Saltmarsh Ribbonwood >>> Rushes > >	Clubrush > > Kiokio >> Threesquare >>> Orchids
Fish		Not assessed	Not assessed
Pests		Exotic Grasses/Weeds > >	Exotics: Exotic Grasses/Weeds > > Tall Fescue >>> Willow >>> Gorse>>> Finch> Swallow>
Native Vegetation Dominance		50%	15%
Valued Species		39 Traditional vs Current 5	39 Traditional vs Current 7
Takiwā score:		3.6/5.0	2.0/5.0
Abundance score:		8.0	2.0

lakes, water and native fish values were not directly assessed. With the new tool being developed fish species and mahinga kai health will be able to be assessed as well.

Native Species Abundance and Vegetation Dominance

Saltmarsh Ribbonwood was the most prevalent native plant, being found at eight of the 14 sites. Kakī Anau (black swans) were the most commonly encountered taonga bird species, being found at nine sites. Native freshwater fish were not assessed at lake edge sites. Shortfin tuna (eels) were however encountered at a number of river mouth sites.

The most common exotic plants encountered during the fieldwork were exotic pasture grasses and weeds, including Tall Fescue and thistle (12 sites). Willow and gorse were also common (seven sites).

Overall, native species abundance and in particular native vegetation dominance around the lake edge was poor. Seventy percent of sites had less than 15% dominance in native vegetation. Seventeen percent had moderate native vegetation dominance (between 35–65% dominant), but there were no sites with greater than 50% of native vegetation dominance (Figure 3).

E.coli results

E. coli results were poor (Figure 4). Forty two percent of the 12 sites tested failed the national recreational guideline for water quality and no sites achieved the shellfish/food gathering standard or were fit for drinking (Ministry of Health 2000; Ministry for the Environment, 2003—see Appendix A). Alarmingly, *E. coli* at 83% of sites sampled showed resistance to antibiotics, with Ampicillin (a human antibiotic) being the most common (Aitken 2007). The worst record was Greenpark Sands, and the best was Pākoau. More testing, over a greater time frame and using more samples, as well as testing any impacts this *E. coli* may have on fish health would be important to understanding the extent of any serious health or environmental problems.

Te Waihora Cultural Health Tool

As a result of the Ngāi Tahu/NIWA Te Waihora Cultural Health Tool study and in particular the interviews with tangata whenua, a number of unique themes and health indicators for Te Waihora (as well as known generic ones) have emerged, including:

Drivers of Change:

- Catchment land use modification and intensification
- Drainage, management and reclamation of wetlands
- Decline in quantity, quality and access to mahinga kai
- Decline in inflow and lake water quality and quantity

Change over time:

- Loss of mahinga kai habitat
- Loss of matauranga Ngāi Tahu
- Domination of fishery by commercial operators
- Declining access and use of the lake and mahinga kai
- Degradation of mauri of the lake and mana

Desired outcomes:

- Regenerating, restoring native habitat
- Higher and fluctuating lake
- Native birds
- Reduced sediment and erosion
- Integrated management action (resourcing)
- More Ngāi Tahu and community use
- Mahinga kai activity rejuvenated
- Te Kete Ika o Rākaihautū/The Fish Basket of Rākaihautū restored

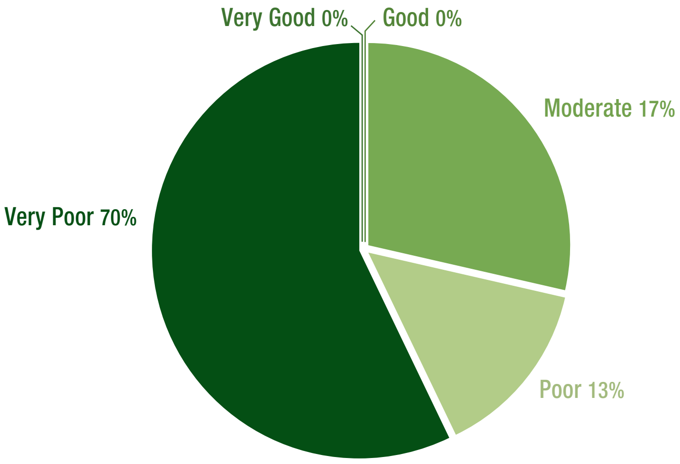

FIGURE 3. Native vegetation results for Te Waihora/Lake Ellesmere monitoring sites.

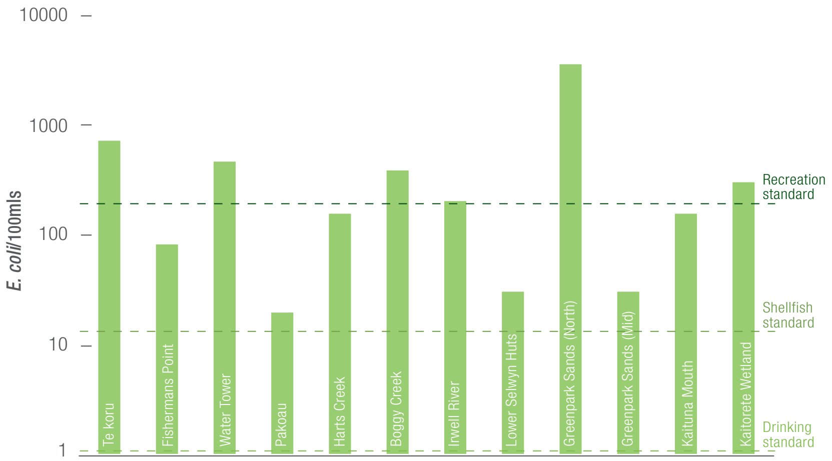

FIGURE 4. *E. coli* results for Te Waihora/Lake Ellesmere monitoring sites.

Management Requirements:

- Protection and enhancement of margins and tributaries
- Implement non-commercial areas
- Lake openings for mahinga kai/ecological values
- Re-establishing aquatic weed beds
- Sustainable waterway management
- Commercial activities managed
- Monitoring of cultural health, including the assessment of individual mahinga kai species such as Tuna, Pātiki, Harakeke and Kakī Anau (see Appendix B).

8.6 Te Whakamutunga Conclusions and Recommendations

Some preliminary conclusions can be drawn. The lake, and in particular the lake edge, still holds significant mahinga kai values, despite obvious water quality, modification, pressure and native vegetation issues.

Although the lake edge received a moderate assessment, water and native fish values were not able to be directly assessed due to a limitation with the Takiwā method.

E. coli results indicate that water quality and quantity are degraded and warrant further more specific investigation to understand overall health.

The development of a specific lake cultural health tool (Jason Arnold/NIWA) will be important to gain a more accurate picture of the cultural health of the lake and the lake edge.

Recommendations from the above are:

- Development and use of a lake cultural health tool and the closer investigation of water quality and quantity and native fish issues for future assessments.
- Inclusion of indicators for water quality, quantity/lake-level, lakebed, native fish and customary food gathering effort and quality within the lake cultural health tool.
- Protection & enhancement of native lake edge vegetation to provide greater habitat for taonga bird and fish species as well as providing a buffer from land use and lake level changes.

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8.8 Appendices

Appendix A Water Quality Standars

Microbiological Water Quality Guidelines for Marine & Freshwater Recreational Areas (Ministry for the Environment 2003)

Freshwater Contact Recreation:

No single sample greater than 260 *E .coli* / 100 mL.

Marine Water Contact Recreation:

No single sample greater than 140 enterococci / 100 mL.

Shellfish Gathering:

The median faecal coliform content of samples taken over a shellfish-gathering season shall not exceed a Most Probable Number (MPN) of 14 / 100 mL, and not more than 10% of samples should exceed an MPN of 43 / 100 mL (using a five-tube decimal dilution test).

New Zealand Drinking Water Standards Ministry of Health 2000

E. coli

The indicator organism chosen to indicate possible faecal contamination of drinking-water is *E. coli*. Thermotolerant coliforms (faecal coliforms) and total coliforms (which include both faecal and environmental coliform bacteria) may also be used to monitor water quality, but the results are harder to interpret than those from *E. coli*. If total coliforms or faecal coliforms are used for drinking-water monitoring to demonstrate compliance with the Standards instead of *E. coli*, a positive result shall be treated as though it were an *E. coli* result.

E. coli should not be present in drinking-water in the distribution zones. However, unlike the drinking-water leaving the treatment plant, whose microbiological quality is under the control of the treatment plant management, the quality of drinking-water in the distribution zones may be subjected to contamination from a variety of influences.

Some of these may arise from poor management practices, such as faulty reservoir construction and maintenance, or poor sanitary practices by water supply workers.

Other contamination sources arise from the water users themselves, such as poor sanitation while making connections to the service or inadequate backflow prevention. *E. coli* may, therefore, occasionally be found in the reticulation. The presence of *E. coli* must always be followed up. If more than 0.2 mg / L free available chlorine (FAC) is maintained in the drinking-water supply reticulation, coliform bacteria and *E. coli* are rarely, if ever, found. For this reason it is permissible to substitute monitoring of FAC for some (but not all) of the *E. coli* monitoring.

Appendix B

Assessing the Cultural Health of Hua Kaki Anau-black swan eggs

Hua Kakī Anau or black swan eggs were identified through initial interviews as one of the key mahinga kai species that should be subject to specific assessment as part of the wider Te Waihora Cultural Health Tool. Swan eggs were a very important seasonal mahinga kai at Te Waihora and Ngāi Tahu have a long association with the collection of bird eggs generally. Therefore an informal assessment of swan egg health was carried out in conjunction with the 2007 seasonal customary harvest.

Under the authority of the Acclimatisation Society earlier last century swan egg collection became an illegal activity. Rangers were employed to camp up towers overlooking the swan breeding areas to deter would be egg gatherers. In the 1960s there were over 80,000 birds, but the population crashed after the Wahine storm in 1968 with a recovered population of between 4–10,000 currently.

A permit to gather eggs was recently granted to Ngāi Tahu by the North Canterbury Fish and Game Council. Notwithstanding the Council process there are still a number of barriers to returning to this cultural practice. The swans nest largely on private land and access is limited by 4wd vehicle or boat depending on landowner consent. The site is also severely degraded in terms of the indigenous vegetation and erosion is rapidly destroying the main nesting area. Further research and understanding is needed to ensure this is a sustainable practice into the future. Using the Cultural Health Assessment forms specifically for swan egging it is hoped that a valuable dataset can be obtained to support a sustainable mahinga kai practice.

As part of the swan egg harvest, a thorough nest and egg count was carried out in conjunction with Fish and Game North Canterbury. A total of 368 nests were found with 1,537 eggs recorded at an average of 4.17 eggs per nest. Following the first legal swan egging in what is thought to be over a century, there were many positive reports of sponges, birthday cakes, omelettes and scrambled eggs. Mātauranga (knowledge) was also shared by kaumātua with rangatahi ensuring this practice is continued.

Photo **The protection and enhancement of lake edge vegetation provides greater habitat for bird and fish species as well as providing a buffer from land use and fluctuating lake levels.** Photography **Colin Hill.**


SHELLEY McMURTRIE

09

RECREATION values

KAY L. BOOTH Lindis Consulting

This report presents findings from a study of recreation values, opportunities and issues associated with Te Waihora/Lake Ellesmere and its margins. The study collated existing information and contacted knowledgeable individuals. An assessment of the current recreational use of the lake and its margins identified a wide range of water- and land-based activities. The lake is nationally significant for waterfowl hunting, and regionally significant for fishing and cycling on the rail trail. It is rated as a nationally significant water body for recreation. Activities are reliant on a healthy natural ecosystem, especially fish and wildlife habitat. Land-based recreation infrastructure is run-down and needs refurbishment. There are various 'drivers' of recreational use of the lake and its management. They include the lake's environmental state, the lake level, public access, awareness and information, recreation facilities, the Little River rail trail, the existence of alternative recreation sites, the recreation 'catchment' for users, recreational trends and effects, and an inadequate database for decision-making. A recreation vision is proposed: A healthy recreation resource that is well used and valued. To achieve this vision, the resource needs to be enhanced so it better caters for existing uses and users, and entices people to visit so they may 'connect' with the lake.

9.1 Introduction

Purpose and objectives

This report presents findings from a study of recreation values, opportunities and issues associated with Te Waihora/Lake Ellesmere ('the lake') and its margins. The study was undertaken in preparation for the Living Lake Symposium (November 2007), the purpose of which was to bring together the current state of knowledge on the lake and its catchment; identify gaps, key indicators and key management issues; and to form the basis of a collaborative management approach for improving the ecological health of the lake and its catchment.

The study had six objectives:

- To describe current recreational use of the lake and its margins
- To compare current use with the assessment of recreational use provided by Blackford and Law in 1996
- To highlight potential opportunities for recreation
- To identify resource characteristics upon which lake-related recreation relies, including infrastructure requirements
- To discuss issues for lake recreation, including the influence of lake management on recreational activities
- To identify long-term goals for lake-related recreation, and indicators that would reflect progress toward those goals.

Study approach

The study collated existing information about recreation associated with the lake and its margins. Key sources were the 'Inventory of Recreation Values for Rivers and Lakes of Canterbury, New Zealand' (Sutherland-Downing and Elley, 2004), the Joint Management Plan for the lake (TRONT and DOC, 2005), draft reserve management plans for Lakeside Domain and Coes Ford (Lucas Associates, 2007a, 2007b) and fishing evidence by Millichamp (2005). Primary data were not collected, beyond informal participant observation during field visits, because of the winter/spring study period. Owing to a dearth of existing research material, individuals identified as knowledgeable about the Lake were contacted for information. Appendix A lists these individuals, who are referred to as 'key informants' in this report.

Existing information about Lake-related recreation

There is a lack of empirical data about the recreational use of the lake and its margins. The only quantitative data identified during this study were angler statistics from the national anglers survey (Unwin and Brown, 1998; Unwin and Image, 2003) and counts of registered mai mais (Fish & Game New Zealand records). As a result, Lake-related decision-making has an inadequate information base for recreation.

Previous work has focused upon describing recreational opportunities, use and issues. This report updates this work for 2007 (with particular reference to changes since a 1996 study by Blackford and Law) but also examines the underlying causes of recreational change. It examines the style of, and context for, lake-related recreational activity, identifies factors that influence lake-related use, presents ideas for future recreation opportunities, and specifies recreation outcomes and indicators for future management.

Photo **The Lake is nationally significant for waterfowl hunting.** Photography **Shelley McMurtrie.**

Definitions

Lake-related recreation pertains to all recreational opportunities associated with the waters of the lake and land margins surrounding the lake. This encompasses all types of leisure pursuits, both commercial and non-commercial activities. The report does not encompass customary activity or cultural harvest.

The study area is delimited by the roadside boundaries that circumscribe the lake: Lower Lake Road, Lake Road, Pannetts Road, Davidsons Road, Ridge Road, Seabridge Road, State Highway 75 (SH75) and Bayleys Road (Figure 1).

Report outline

This report first describes the nature of existing lake-related recreation (Section 9.2), including comparison with information from the mid-1990s (Blackford and Law, 1996). Factors influencing lake-related recreation and characteristics of the resource important for recreation are discussed in Section 9.3, together with issues related to lake management. Section 9.4 discusses five opportunities that would enhance recreational values of the lake. A recreation vision and outcomes are presented in Section 5, matched with indicators which will identify progress towards their achievement. Section 9.6 contains recommendations for future management and research actions.

9.2 Current state of recreational use

This section presents a description of the current (2007) recreational use of Te Waihora/Lake Ellesmere and its margins. The discussion is structured by activity type. It compares current information with the 1996 statement of lake-related recreation, provided by Blackford and Law, and identifies issues associated with activities, where relevant. Key information from this section is summarised first.

Key points

- A wide range of water- and land-based activities, including fishing, waterfowl hunting, bird-watching, water sports (waterskiing, kayaking, etc), picnicking, camping, cycling, trail biking, volunteerism (conservation and recreation projects) and scenic driving
- National significance for waterfowl hunting; regional significance for fishing and cycling on the rail trail; local significance for other activities. Rated as a nationally significant water body for recreation (MfE, 2004)
- Lake attractions are the availability of a specific resource (e.g. waterfowl; rail trail) and/or convenience (close to home)
- Participation increases since 1996: Cycling on the rail trail and volunteerism. Decrease: Trout fishing. Participation in other activities appears stable or declining. Most of the recreation issues documented in 1996 by Blackford and Law continue to be relevant in 2007, despite some change in the mix of activities undertaken
- Activities are reliant on a healthy natural ecosystem, especially fish and wildlife habitat
- Land-based recreation infrastructure is run-down and needs refurbishment.

Photo **The Lake has the potential to be an internationally significant bird-watching site.** Photography **Shelley McMurtrie.**

Wildlife-dependent recreation

Fishing

The lake and lower reaches of its tributaries are regionally significant[1] for trout fishing and whitebaiting, and locally significant for other styles of fishing (including coarse fish, flounder and eels). Angling has declined dramatically since the mid-1990s (Table 1). No data are available for whitebaiting, but anecdotal evidence suggests the Lake and lower tributaries are intensely fished when the lake is open to the sea. Recreational fishing for other species appears mainly to be pursued by local residents. No guided fishing was identified, although it may occur in small numbers.

Areas fished recreationally include (TRONT and DOC, 2005):

- Lower reaches of the Selwyn
- LII adjacent to Yarrs Flat
- Harts Creek mouth
- Halswell River and canal mouth
- Irwell River
- Lake opening area
- Kaituna River lower reaches and mouth
- Various lake areas for eel, flounder, mullet and whitebait.

The data from Table 1 and the summary presented in Table 2 suggest that:

- Both the lake and its tributaries are important for fishing
- Key types of fishing are trout angling and whitebaiting
- There has been a dramatic decline in trout angling
- Overall, access for fishing is good.

Whitebaiting occurs on both sides of the lake outlet after the lake is opened and on lower reaches of lake tributaries. The activity attracts people from around Canterbury and the season is dictated by the lake opening (when whitebait can enter the lake). It appears that very little recreational eeling and floundering takes place (Table 2 appears to over-state these types of fishing), however, the opportunity to do so is important to local residents.

The 1996 report (by Blackford and Law) noted access issues for fishing, and the Joint Management Plan for the Lake (TRONT and DOC, 1995) notes that unformed legal roads are sometimes difficult to identify or navigate. Access for fishing has improved since the Fish & Game New Zealand signage programme was implemented in the mid-1990s (access is discussed in Section 9.3: Access). The 1996 report also noted that poor water quality and timing of the lake opening were significant factors affecting the quality of fishing. Both these points remain valid in 2007, as well as the documented decrease in trout numbers (Ross, 2004 cited in Millichamp, 2005).

TABLE 1. **Angler days spent in Te Waihora/Lake Ellesmere and its tributaries in the 1994/95 and 2001/02 seasons (Unwin and Brown, 1998; Unwin and Image, 2003 cited in Millichamp, 2005).**

River	Angler Days 1994/95 season	Angler days 2001/02 season	% change
LII	2,132	681	-68%
Selwyn	6,702	2,177	-68%
Irwell	433	35	-92%
Harts Creek	1,008	483	-52%
Halswell	1,760	221	-87%
Hororata	160	0	-100%
Lake Ellesmere	424	152	-67%
Total	**12,619**	**3,749**	**-70%**

TABLE 2. **Recreation fishing summary (Sutherland-Downing and Elley, 2004).**

Waterway	Species	Accessibility	Recreation Frequency [2]	Recreation Intensity[2]
Lower Selwyn	Very common: eels; Common: coarse fish, trout	Limited along bank/bed; good from road; good from boat	High: trout; Medium: white-baiting, eeling, other fishing	High: trout; Medium: white-baiting, eeling, other fishing
LII	Very common: eels; Common: coarse fish, trout	Limited on bank, good for road and boat	Medium: trout, white-baiting, eeling, other fishing	Medium: trout, white-baiting; Low: eeling, other fishing
Halswell	Very common: eel; Common: coarse fish, trout	Good from bank, road and boat	Medium: eeling; Low: trout, white-baiting, other fishing	Medium: eeling; Low: trout, white-baiting, other fishing
Irwell	Common: trout	Good access from bank, road and boat	Low: trout, eeling	Low: trout, eeling
Harts Creek	Very common: eels, trout	Limited bank access, good road and boat access	High: trout; Medium: eeling; Low: white-baiting	Medium: trout, eeling; Low: white-baiting
Lake Ellesmere (Te Waihora)	Very common: whitebait, flounder, eels, mullet; Common: coarse fish; Uncommon: trout	Good for all three classes	High: white-baiting; Medium: trout, eeling, other fishing	High: white-baiting; Medium: trout, eeling, other fishing

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[1] There is no accepted method to assess recreation significance. This assessment covers facets of use (estimated user numbers, user 'catchment') and the resource (availability of substitute sites, uniqueness and quality of resource characteristics). Because it has relied on secondary data, the assessment is indicative only.

[2] Recreation frequency is defined as how often a river or lake is used for recreation, while recreation intensity relates to the number of people who use the water body

Waterfowl hunting

The lake and its margins are nationally important for waterfowl hunting. The lake has been called “New Zealand’s most popular recreational duck-shooting area”[3] and “one of the premier gamebird hunting areas in New Zealand” (Fish & Game New Zealand, 1998:11). More specifically, Fish & Game New Zealand state that their North Canterbury region offers the best Canada goose hunting in the country (Te Waihora/Lake Ellesmere hosts the largest Canada goose population in Canterbury)[4].

Hunting appears to have remained reasonably stable over the past 10 years. The 1996 report considered the lake to be the single most important waterfowl hunting area in the region, both in terms of hunter effort (hunting days/hunter) and total seasonal harvest per hunter. This remains true in 2007. Although the National Gamebird Harvest Survey does not separately specify Te Waihora/Lake Ellesmere, data indicate a static hunting situation in Canterbury (pers. comm. Steve Terry, Fish & Game New Zealand, 2007).

The lake supports in excess of 30,000 waterfowl (TRONT and DOC, 2005). Species hunted include mallard ducks (the most popular and abundant bird; May and June), Canada goose (May to November and February to April), black swan and shoveler duck (July to November). A small amount of guiding occurs.

Hunting occurs all around the lake. Key hunting areas are (TRONT and DOC, 2005): Adjoining Lower Selwyn Huts, Greenpark Sands, Yarrs Flat, Irwell River, Boggy Creek, Lakeside Reserve, adjoining Harts Creek Wildlife Refuge, Kaitorete Spit shoreline, Kaituna Lagoon. There are 398 registered usable mai mais (202 on Ngāi Tahu land, 74 on DOC-administered land, 122 on private land) (Fish & Game New Zealand records).

The 1996 report noted issues for hunting that were associated with waterfowl habitat loss and degradation, as well as access issues. Since 1996, Fish & Game New Zealand access signposting has assisted with access provision, although some specific sites remain contentious. Fluctuating lake levels affect mai mai access.

Bird watching

The lake is potentially an internationally important bird-watching site owing to the abundance, diversity and rarity of species present, however, the amount of current use appears to be small. No data exist to confirm numbers of bird-watchers. This non-extractive wildlife activity is undertaken as both organised and independent trips, usually the latter. Some commercial trips take place, but their frequency appears to be very low. Te Waihora/Lake Ellesmere bird-watchers include international ‘birders’. The Canterbury branch of the Ornithological

FIGURE 1. Map of study area (source of base map: TRONT and DOC, 2005). Base Map sourced from ECan.

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[3] http://www.doc.govt.nz/templates/ActivitiesSummary.aspx?id=35303, accessed 15 Oct 2007
[4] http://www.fishandgame.org.nz/Site/Regions/NorthCanterbury/hunting.aspx, accessed 15 Oct 2007

Society undertakes four trips to the Lake each year, including bird-counting trips, attracting about 12-20 people on each trip.

Popular locations for bird-watching are:

- Kaituna Lagoon: popular because of easy access but not ideal for bird spotting
- Sunset Point (Ataahua) near corner of lagoon: accessible from SH75, this site is popular with international bird-watchers
- Greenpark Sands (Embankment Road/ Jarvis Road): good viewing for wading birds but not good if the lake is too high or low
- Yarrs Flat: public access is not sign-posted
- Harts Creek: publicly-accessible bird-watching hide; the boardwalk is a popular spotting location
- Fisherman's Point/Taumutu: for views of birds at the tip of Kaitorete Spit
- Western end of Kaitorete Spit: access is difficult towards the end, as the road is not formed. Some access problems in the lambing season.

The preferred time for bird-watching is November to February, but the activity also occurs in March/April and September/ October (TRONT and DOC, 2005). These times mostly relate to the presence of migratory birds.

It was suggested by one bird-watcher that the internet has made bird-watching information more available, and this has increased the popularity of the lake for this activity. No data exist to verify this trend.

Despite its potential high value for bird-watching, the lake receives relatively little coverage on relevant websites (e.g. Royal Forest and Bird Protection Society 'Where to see birds in New Zealand' pages do not mention the lake[5]; few tourism companies that offer New Zealand birding tours mention the lake on their website[6]). However, the Ornithological Society website links to trips to the lake offered by the Canterbury branch[7], the Little River Rail Trail website notes the presence of prolific birdlife as a feature of the Rail Trail[8] and Harts Creek bird hide is noted on the DOC website[9].

Recreational conflict between birders and other recreationists appears to be relatively minor. The 1996 report noted some perceived conflict with waterfowl hunters but different seasons were thought to 'solve' this problem. Habitat and bird disturbance by motorised vehicles/boats was noted (1996). The vehicle issue is likely to be largely resolved by implementation of the Joint Management Plan (TRONT and DOC, 2005).

The key issue is threats to the birds (the recreation attraction) through habitat modification, an issue noted in 1996. Blackford and Law also noted disturbance by land-yachts on sand-flats (north-eastern margins of Lake), however this has been resolved since these vehicles can no longer access the area (see later). The Rail Trail has opened up access and, to date, cyclists do not appear to be a problem for bird-watcers.The Ornithological Society is working to improve access instructions for 'birders'.

Water sports

The area surrounding Lakeside Domain is the focal point for water sports, including sailing, water skiing, power boating, jet skiing (personal water craft), windsurfing, kitesurfing and kayaking. Kayaking also occurs at several other locations, including the lower reaches of the LII and Selwyn rivers. The Joint Management Plan (TRONT and DOC, 2005) suggests that these activities now occur at lower use levels than in past years. Information from key informants contacted for this study supports this view. Reasons for the decline appear to be an increase in alternative water bodies (e.g. Roto Kohatu for jetskiing) and downward participation trends (e.g. windsurfing).

The Ellesmere Aquatic Club is based at Lakeside Domain, where its clubrooms are located. It has had a stable membership of around 30-35 families for 20-30 years. The club has kayaks and small yachts (optimists) available for use, but does not offer formal lessons. The club was formerly used by schools but this use has declined because a high lake level could not be guaranteed.

The New Zealand Jet Boat Association used to hold events on the lake ('many years ago') but no longer does so. A small amount of local power boat use occurs. The Windsurf New Zealand website provides access information for Lakeside Domain and information about the best wind conditions for sailing at that location. It notes that "Lake Ellesmere is a popular sailing spot for people who live on the southern edge of the city or small townships south of Christchurch"[10]. In the past, both windsurfing and kitesurfing events have been held at the lake. Key informants noted that the Avon/Heathcote Estuary is more convenient for Christchurch residents and they usually hold events there.

The area surrounding the Domain is zoned for watercraft activity. The Environment Canterbury navigation safety bro-

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[5] http://www.forestandbird.org.nz/enjoy_nature/birds/information.asp, accessed 15 Oct 2007

[6] e.g., http://www.naturequest.co.nz, http://www.kiwi-wildlife.co.nz, accessed 20 Oct 2007

[7] http://osnz.org.nz, accessed 15 Oct 2007

[8] http://www.littleriverrailtrail.org.nz/rail-trail/wildlife, accessed 15 Oct 2007

[9] http://www.doc.govt.nz/templates/ActivitiesSummary.aspx?id=35303, accessed 15 Oct 2007

[10] http://www.windsurf.co.nz/windsurf_locations_canterbury.asp, accessed 15 Oct 2007

chure for the Lake includes a map of boat use lanes and access for the Lakeside Domain area. Multiple signage at the Domain is confusing and the water activity rules difficult to interpret. The Lakeside Domain Draft Management Plan (Lucas Associates, 2007a) identifies some recreation conflict between water users (e.g. fishing (nets) versus windsurfers). Boating is prohibited within Harts Creek Wildlife Refuge (TRONT and DOC, 2005).

The 1996 report noted multiple issues for water sports. Those that appear to remain valid in 2007 are:

- Lake levels - need to be high for boat use
- Low lake level creates access issues at Selwyn river mouth
- Lakeside Domain has some issues of craft conflict - noise levels and choppy wake of motorised craft
- Water quality a concern
- Lake not visually appealing for contact recreation
- Swimming in lake and rivers becoming less popular because of visual quality of water.


Photo **Trout fishing has declined dramatically since the mid-1990s.** *Photography* **Ross Millichamp.**

Land-based recreation

Motorised vehicles

The 1996 report discussed land-yachting (now called blokarts), trail-biking and other vehicular activities. Since 1996, land-yachting/blokarting has ceased in the study area. The Joint Management Plan (TRONT and DOC, 2005) identifies areas where vehicular activity is permitted; these areas exclude blokarting. Blokarts cannot use Ngāi Tahu land, and access to Gray's Farm (in the NE), which blokarters previously used, is prohibited across public conservation land. However, technological advances have seen the size of blokarts decrease and alternative sites suitable for blokarts correspondingly increase.

Trail biking and 4-wheel driving is a problem at Coes Ford and is discussed in the Draft Coes Ford Management Plan (Lucas Associates, 2007b). The Draft Plan notes increased vehicular activity in recent years, with 4-wheel driving activity at the edges of and in the riverbed. Some areas of the reserve are used by motorcycles, particularly trail bikes. Conflict exists between recreational vehicle drivers and most other users. This includes nuisance factors of noise and public safety, as well as environmental damage. The Draft Plan notes that speed restrictions are often not observed.

Similarly, the Lakeside Domain Draft Management Plan (Lucas Associates, 2007a) identifies that motorised bikes and trail bikes are used in the reserve. There is some conflict between users, invoking safety issues. Fences have been cut down to facilitate driving and the Draft Plan notes a lack of signage to deter speeding.

Cycling: Little River Rail Trail

The Little River Rail Trail dramatically increased cycling as a lake-related activity when it opened in 2006. The rail trail section from Motukarara to Birdlings Flat runs alongside the eastern end of Te Waihora/Lake Ellesmere and was the first section of the rail trail to open. The trail has become very popular, with an estimated 15,000 visits in its first year (pers. comm. Dave Milward, DOC, 2007). While open to cyclists, walkers and runners, it is most used by cyclists and has quickly become a significant regional recreation destination/activity.

The website for the rail trail notes significant natural, cultural and historical sites of interest along the Motukarara-Birdlings Flat section of the trail[11]. One part of the trail 'bridges' the lake, with water on both sides. A car park was built and landscaped at Ataahua Reserve (Kaituna Quarry) by the Hornby Rotary Club in 2007. A toilet has been recently constructed at the quarry.

Picnicking and related activities

Land-based 'passive' activities which occur around the lake include picnicking, photography and generally enjoying wide-open spaces (TRONT and DOC, 2005). The two primary land-based activity nodes are Lakeside Domain and Coes Ford. Other areas used for this type of activity are listed in the Joint Management Plan (TRONT and DOC, 2005) and include: Harts Creek walkway (provides access to part of western shore and bird hide), Selwyn delta, Kaituna Lagoon (access from SH75), Fishermans Point, Kaitorete Spit, and Greenpark Sands (especially from the end of Embankment Road).

The Selwyn District Council manages Coes Ford Recreation Reserve and Lakeside Domain Recreation Reserve. The Council acknowledges that "each of these picnic and paddling areas is in need of a makeover to improve safety, scenery and recreational opportunities"[12] and, for this reason, the Council has commissioned reserve management plans (Lucas Associates, 2007a, 2007b).

Anecdotal evidence indicates that Coes Ford, once a popular summer camping and picnic spot for Cantabrians, has experienced a substantial decline in this type of usage. The Draft Plan suggests that family camping has decreased in the reserve and semi-permanent campers have taken up residence. It recommends repositioning the reserve as a family camping area. Campers use Lakeside Domain during the summer, especially during the summer school

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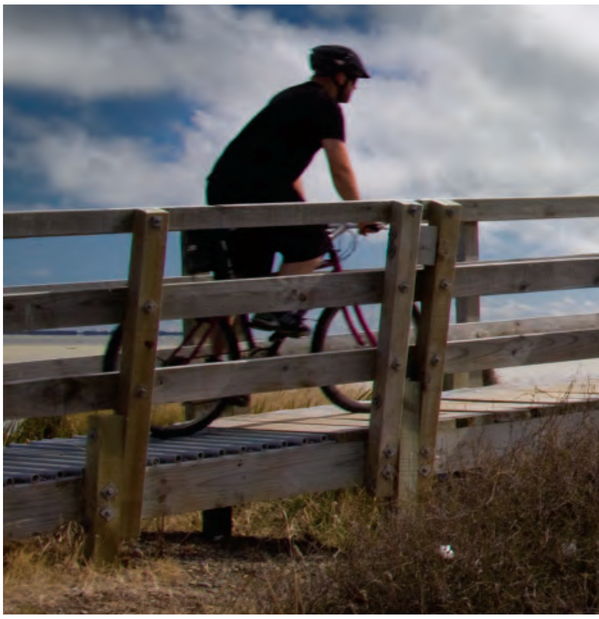
[11] http://www.littleriverrailtrail.org.nz/rail-trail/section5, accessed 15 Oct 2007

[12] 'Parks, reserves & open spaces', http://www.selwyn.govt.nz, accessed 20 October 2007

TABLE 3. **Frequency and intensity of land-based passive activities (Sutherland-Downing and Elley, 2004).**

Activity	Recreation Frequency / Intensity	Location
Sightseeing	Medium / medium	Lake
Walking	Low / low	Lake
	Medium / medium	Lower Selwyn, Irwell River, Harts Creek, Halswell River
	Medium / -	LII
Picnicking/barbecuing	Medium /medium	Lake, Lower Selwyn, Irwell River, Harts Creek, Halswell River
	Medium / -	LII
Camping	Medium / medium	Lake, Irwell River
	Low / high	Lower Selwyn, Halswell River
	Low / low	Harts Creek
	Low / -	LII
Swimming	High / high	Lower Selwyn, L11, Irwell River
	Low / low	Harts Creek, Halswell River
Paddling/wading	High / high	Lower Selwyn, L11, Irwell River
	Low / low	Harts Creek, Halswell River



holidays (Lucas Associates, 2007a). Mobile homes park in the reserve throughout the year.

Water quality at Coes Ford is an issue for swimming. The Selwyn River at the ford has consistently received a 'poor' water quality grade since 2003 (Lucas Associates, 2007b), as measured by Environment Canterbury using a 5-point scale from very good to very poor, with fair as the mid-point.[13] 'Poor' status indicates the river is "Generally not suitable for swimming ... Swimming should be avoided..." [14] and signage should be posted to alert users. This has been done in the past - however, despite a 'poor' grade at the time of this study (October 2007), no signs were evident. Lakeside Domain maintained a 'fair' water quality grade over the 2005/06 summer (Lucas Associates, 2007a), and at the time of this study (October 2007). This indicates that the water is "Generally satisfactory for swimming, though there are many potential sources of faecal material. Caution should be taken during periods of high rainfall, and swimming avoided if water is discoloured".[14]

Educational activities take place at Ngati Moki Marae (Taumutu) and around the lake generally, especially school and university field trips. The Waihora Ellesmere Trust runs lake field trips, as do other organisations

An eco-tourism business operated for approximately 5 years in the mid-1990s and took around 3,000-4,000 people to the lake during this time period. Trips mainly attracted local Christchurch people, many of whom were repeat clients. Trips visited local attractions, including Harts Creek bird hide, the eel farm, Lakeside Domain, Coes Ford and Selwyn Huts. Tours ceased when the sole operator chose to discontinue them.

The inventory of recreation values for Canterbury rivers and lakes (Sutherland-Downing and Elley, 2004) summarises information about land-based passive activities, and relevant information has been compiled as Table 3.

Low patronage is likely to be related to the perceived poor water quality, lack of aesthetic attractiveness and lack of knowledge about the area (see Section 9.3). These issues compare with the major concern identified in the 1996 report, which was access.

Volunteerism

This activity relates to individuals spending their leisure time undertaking voluntary 'work' on projects associated with nature/historic conservation (such as ecological restoration) or recreation infrastructure (such as the Little River Rail Trail). Not mentioned as an activity in the 1996 recreation study, the global growth in volunteerism over the past ten years is evident in the study area. There are various community groups involved in ecological restoration projects around the lake, such as Green Footprint Project[15] planting days and the Harts Creek Streamcare Group project to clean up and facilitate recreational use at Harts Creek. In addition, lakeside recreation facilities have been constructed by community groups, such as the Ellesmere Lions Club (Harts Creek bird hide and walkway) and the Hornby Rotary Club (Kaituna Quarry car park).

The New Zealand Ecological Restoration Network lists the following restoration sites on their website[16]:

- Harts Creek: Community involvement: private, Fish & Game New Zealand
- Kaitorete Spit: Community involvement: Taumutu Rūnanga, DOC, Landcare Research, Habitat Restoration Services
- Halswell River and Selwyn River: Listed but pages not available.

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[13] http://www.ecan.govt.nz/Our+Environment/Water/SwimmingWaterQuality/Sites/Central-Canterbury-Plains.htm, accessed 20 Oct 2007

[14] http://www.ecan.govt.nz/Our+Environment/Water/SwimmingWaterQuality/FAQ/swimming-water-gradings.htm, accessed 20 Oct 2007

[15] The Green Footprint Project is a collaboration between the Youth Hostel Association, Selwyn District Council, the Waihora Ellesmere Trust and Landcare Research

[16] http://www.bush.org.nz/site/canterbury.html#100000109, accessed 15 Oct 2007

Photo ***The Little River Rail Trail provides a connection with the Lake.*** *Photography* ***Shelley McMurtrie.***

Scenic driving

This activity is associated with 'Sunday drivers' who are sightseeing. Most recreationists on car-outings near the Lake drive along SH75 and view the lake 'by default' - they are not intending to visit the lake. SH75 users represent the group with the greatest potential to enhance their 'lake connection'. The idea of a lakeside visitor centre is discussed in Section 9.4: Lake visitors centre.

National significance assessments

The Ministry for the Environment's (2004) report on freshwater bodies of national importance for recreation lists Te Waihora/ Lake Ellesmere as one of the 105 nationally important water bodies. The lake was included owing to its Water Conservation Order and status as a 'wetland of national importance', not because of usage (although whitebaiters and hunters, including duck shooters, were under-represented in the use surveys and so lake recreation will be under-estimated). The lake is not listed as a water body of national importance for tourism (Ministry of Tourism, 2004)[17]. This conclusion is based on the absence of existing tourist activity in/around the lake. Te Waihora/Lake Ellesmere is not a tourism 'destination' (see Section 9.3: Awareness and infomation).

9.3 Factors influencing lake-related recreation

This section discusses factors that influence or 'drive' recreational use of the lake. These include:

- Resource characteristics which are important features of the recreation setting (Sections 9.3: Enviromental state-Little River Rail Trail). These factors can be influenced by lake managers and are discussed first.
- Parameters which influence lake-related recreation but are 'external' to the lake (Sections 9.3: Alternative recreation sites-Recreational trends). Lake managers cannot directly influence these factors
- Other factors (Sections 9.3: Recreational effects and Lack of data).

Environmental state

The recreation pursued around Te Waihora/Lake Ellesmere is resource-based, that is, it is dependent upon the natural environment. If the quality of the natural resource declines, so too does the quality of the recreational experience. This is the most important factor influencing lake-related recreation.

A dominant theme from discussions with key informants was the poor water quality of the lake and tributaries. This is verified by Environment Canterbury's water quality monitor for swimming sites, which includes Lakeside and the Selwyn River (Upper Huts and Coes Ford), as discussed earlier.

Two points are notable:

- Existing recreational use is occurring irrespective of the current environmental state. However, the only trends data available for any recreational activity (angling) indicates decreasing use levels. Activities which have increased do not involve water contact (i.e. cycling, volunteerism)
- An improvement in environmental quality will enhance the quality of the recreational experience but it cannot be assumed this will result in increased recreational use (i.e. the quantity or number of users).

The riparian margins are an important

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[17] Canterbury waterbodies identified as nationally important for tourism: Avon, Waimakariri, Rangitata and Rakaia Rivers. Importance attributes are the tourism activities that they support (punting, jet boating, fishing, rafting, etc). Freshwater bodies that were important solely for their scenic value were excluded.

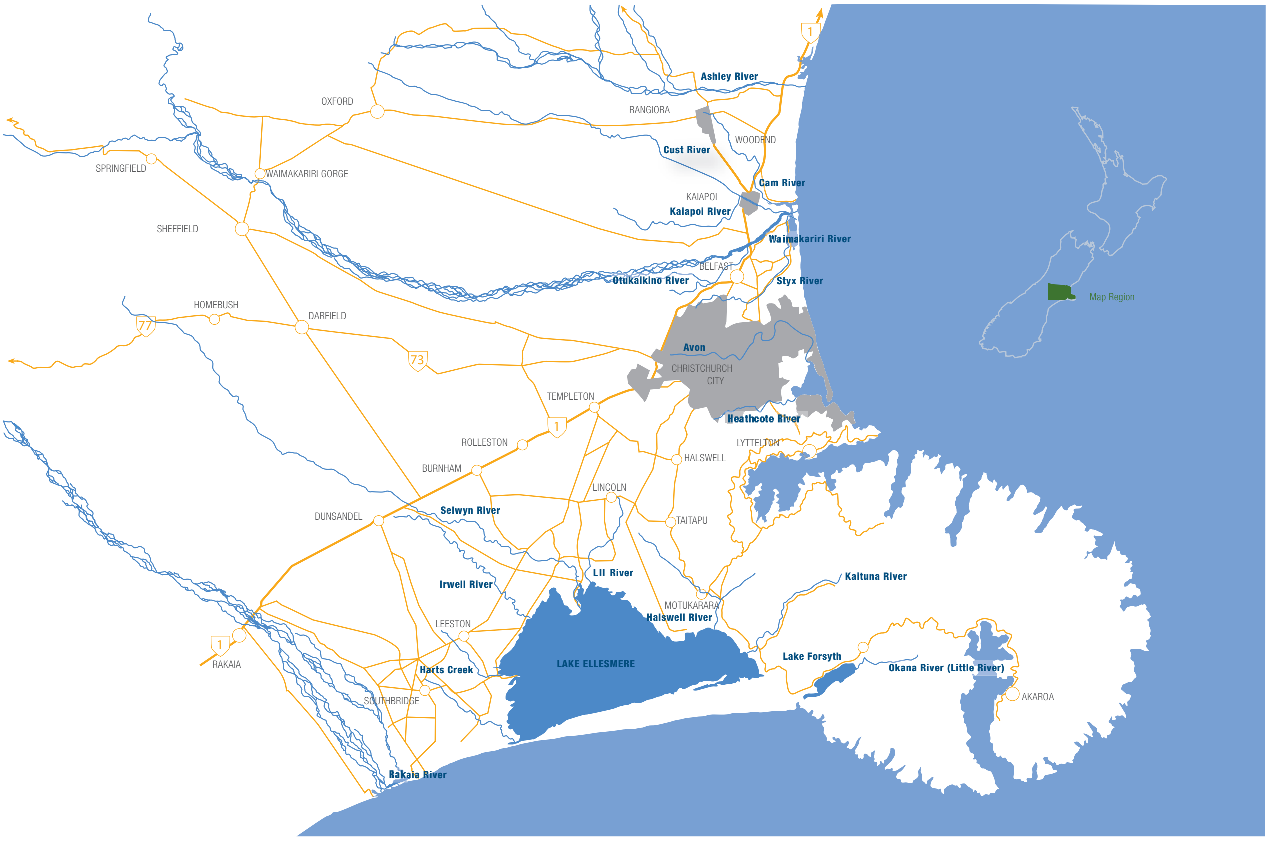

FIGURE 2. Fish & Game 'Close to Christchurch' access map.

FIGURE 3. Access sign at Harts Creek.

facet of the recreational setting. A holistic approach to management of the lake environment (the recreation setting) is required for recreational purposes.

Lake level

Key informants expressed concern about the timing of the lake opening and the extent of lake fluctuation. There appears to be no 'ideal' lake level for recreation, owing to the diversity of activities and their differing requirements. For example, whitebaiters are concerned about maintenance of the fishery, while bird-watchers prefer more frequent lake openings with less fluctuation. A higher lake is not ideal for bird watchers as the Greenpark Sands are under water, although Kaitorete Spit remains accessible for the activity.

This study has found that:

- Lake level dictates the ability to pursue certain recreational activities, or suitable places for the activity
- A constant Lake level appears to be desirable for most recreation purposes
- Users' uncertainty about the level of the Lake is an issue, although Environment Canterbury offers a user-pays Lake level telephone information service (a co-ordinated web-based information portal is proposed in Section 9.4: Education and interpretation)
- It is desirable that the needs of recreationists are taken into account with respect to Lake level management. This would require input from the range of recreational interests.

People need reliable access points to the lake and a fluctuating lake level can interrupt this reliability, as areas get boggy and unpassable. Similarly, where boardwalks and bridges become 'wet' with high lake levels, this can be a problem.

Access

Access provision to the Lake is adequate, although some site-specific issues exist (usually concerning landholders' rights and needs). The Joint Management Plan (TRONT and DOC, 2005) maps legal public access areas/routes and identifies ten key foot lake access points and seven key boat access points. The plan has policies to provide, enhance and maintain these access points, as well as provide public information about them.

Since the 1996 study, Fish & Game New Zealand has improved lake access provision with their nation-wide programme of access negotiation and signage. The organisation provides an access map 'Close to Christchurch' which gives instructions on access and a map showing access points around the lake (Figure 2). Designated access points correspond with on-site signage (Figure 3), although some has yet to be put in. These accessways signal public access and provide access for all recreationists (not just fishers and hunters). Informal access exists where locals and those 'in the know' have arrangements with private landholders to cross their land, or know public accessways that are not signposted.

Little road signage exists, with the exception of road signs for Lakeside Domain and Coes Ford, the two primary land-based recreation sites. This contrasts with other recreation areas, for example popular beaches, where road signage indicates roads which provide beach access. If recreationists cannot find the lake or river access point, they will not be able to undertake their recreational activity.

Awareness and information

An overarching factor influencing lake recreation is awareness of the recreation resource. The lake has a low profile on visitor related web sites and in guidebooks (see, for example, Bain *et al.*, 2006). Most of the general information and specific access information provided appears to assume some prior knowledge of the lake. A key informant who used to run guided tours noted that few Christchurch people had been to the lake before coming on the tour.

A corollary is that the lake is not a recognised visitor destination. It lacks identifiable places for the public to go and things to do, with a few exceptions (e.g. Coes Ford for picnicking). This compares with recreation sites such as Bottle Lake Forest Park or Sumner, which are known 'destinations' with known recreation opportunities. Suggestions for over-coming this 'problem' are presented in Section 9.4.

Recreation facilities

Recreation facilities around the lake take the form of basic infrastructure, including signage, toilets, picnic tables, camping areas, boat ramps and jetties. Some facilities are in a poor state of repair and require replacement or maintenance (see Figure 4). In sum, a 'tidy up' is required.

The 'simple' nature of the facility provision is appropriate for the current mix of activities. Indeed, some key informants expressed an interest in keeping the lake infrastructure basic they didn't want 'flash' facilities. However, these are existing users, for whom existing conditions suit. An exception to this recommendation is the proposed lake visitor centre (see Section 9.4: Lake visitor centre).

Sites around the Lake are not connected. Some walking/cycling tracks between recreation nodes (e.g. Lakeside Domain and Harts Creek) would be beneficial. See Section 9.4: Kayaking, for discussion of the proposed Lake cycle trail.

Little River Rail Trail

The development of the rail trail has been a success story for the lake because it provides a 'connection' with the lake for the public. This positive outcome has occurred by default, in that the rail trail is centred upon the rail route, not the lake. However, it illustrates the potential for greater 'connection' of the public through recreational activities. This idea is pursued in Section 9.4 via a range of potential opportunities.

Alternative recreation sites

Te Waihora/Lake Ellesmere is a unique recreation resource for some activities, while other lake-related activities can be satisfied elsewhere. Water sports have declined at the lake, in part owing to the provision of alternative sites. Activities for which the lake offers a unique or special resource, with few substitute sites, are the wildlife-related activities (discussed in Section 9.2: Wildlife-dependent recreation) and cycling on the rail trail.Potential opportunities discussed in Section 9.4 build upon these special resource characteristics for bird-watching and cycling. Similarly, the opportunity for culture-based activities is discussed later, as yet, an untapped 'resource' (although included within some educational field trips).

Recreational 'catchment'

At a local and regional level, Te Waihora/Lake Ellesmere is in close proximity to a growing population base or recreational catchment. Population figures suggest growing numbers of potential recreationists in the immediate area. Table 4 shows the census night 'usually resident population'

FIGURE 4. Entry sign at Coes Ford.

Photo ***Harts Creek is a popular bird-watching site.***
Photography ***Kay Booth.***

TABLE 4. **Population statistics for Christchurch City and Selwyn District (Statistics New Zealand, 2007).**

	1996	2001	2006
Territorial Authority			
Christchurch City	316,608	324,060	348,435
Selwyn District	24,783	27,312	33,666
Ward			
Ellesmere[18]	6948	8304	11379
Springs[19]	5040	5478	5925
Selwyn Central[20]	7302	7509	9780
Banks Peninsula[21]	7581	7833	8166

for Selwyn District and Christchurch City since 1996 (Statistics New Zealand, 2007). Christchurch City recorded a 10% population increase between 2001 and 2006, while Selwyn District showed a 23% increase. The national figure is an 8% increase. Wards of Christchurch City and Selwyn District that are close to the lake are also shown in Table 4. All wards show population increases, especially Ellesmere.

Population projections indicate that the Christchurch City and Selwyn District populations will increase by a projected 14%[22] and 57%, respectively, between 2001 (base figure) and 2026 (medium projection series) (Statistics New Zealand, 2007). This compares with a 22% projected national increase.

Several communities are located near the lake edge: Birdlings Flat, Greenpark Huts, Upper and Lower Selwyn Huts, Lakeside and Taumutu. These residential communities provide a distinct cultural setting for visitors, owing to their rural- and bach-like appearance.

The residents of these neighbouring communities spoken to as part of this study indicated a strong place attachment - in part they lived there because they liked the environment and the recreational opportunities it provided. The ability to recreate around the lake (to go floundering, for example) was very important to them. Recreational values for local residents should not be overlooked.

At the national level, 79% of New Zealanders identify themselves as recreational users of fresh water (BRC, 2004 cited in MfE, 2004). Similarly, New Zealand lakes and rivers feature prominently as tourism attractions (Ministry of Tourism, 2004). In other words, there is strong interest in activities associated with fresh water from both New Zealanders and international visitors. A current study will provide more information about the needs and values of New Zealand river users (Galloway, in prep); its funding by several national agencies indicates the importance of river recreation in New Zealand.

Recreational trends

Recreation is strongly affected by technological change and shifts in user preferences (Devlin and Booth, 1998). Relevant changes were noted in Section 9.2.

Recreational effects

Adverse effects from recreationists upon the environment, and upon other users, appear to be relatively minor at present, with the exception of motorised use of specific sites (especially trail bikes). Sites mentioned by key informants were Coes Ford (conflict with other users), and Taumutu and Kaitorete Spit (environmental effects upon sensitive natural and historic heritage sites). Adverse effects are likely to increase if use levels increase, and may require active management. This is a factor that should be considered as part of the development of lakeside recreation in the future.

Lack of data

While the dearth of research data does not influence recreation per se, it does affect sound decision-making about recreation on and near the lake. Difficulties encountered during this study include:

- Variations in research parameters (across studies) make it difficult to understand/measure use trends
- Different study areas makes comparison difficult
- Because there are many recreational groups involved, it is difficult to comprehensively cover all aspects of recreation.

Inadequate or inefficient recreational planning is a risk, in that many decisions are being made with an inadequate information base, as studies (including this one) have relied on key informants, rather than empirical data. Establishing a meaningful research monitoring programme is challenging, given the large area of interest (multiple sites) and the low use levels of many sites. Cost-effective means of data gathering would require careful planning. Section 9.5 outlines the rudiments of a proposed recreation monitoring programme.

9.4 Potential recreation opportunities

This section discusses five future opportunities which would enhance recreational values of the lake and its margins. These opportunities are at the 'ideas' stage - they require investigation of their feasibility.

Lake visitor centre

A Te Waihora/Lake Ellesmere visitor centre is proposed, to be located beside the lake, possibly at the Kaituna Quarry. A lakeside visitor centre would provide many benefits, including:

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[18] Ellesmere Ward includes Leeston, Southbridge, Dunsandel, Selwyn-Rakaia

[19] Springs Ward includes Lincoln, Springston, Tai Tapu

[20] Selwyn Central Ward includes Rolleston, Springston

[21] Banks Peninsula Ward includes Little River and the eastern side of the Lake

[22] http://www.ccc.govt.nz/christchurch/factsstatsandfigures/population/projections-christchurch.pdf, accessed 20 Oct 2007

- A visitor 'destination'
- A visitor hub for the lake to 'connect' people with the environment
- The opportunity for public education about lake values
- An attraction for cyclists on the rail trail (if sited along the route)
- An opportunity for commercial ventures, such as a café or guided walks/cycle rides
- A centre for community projects to engage with potential volunteers.

As noted earlier, despite its high natural and cultural values, the lake has a low profile within the visitor/tourist information literature - it is not a recognised visitor destination. A visitor centre could address this issue, in part. The primary market for the visitor centre would be SH75 traffic (a stop-over en route to Akaroa), rail trail users, bird-watchers (who may have different needs from other groups) and people who are attracted to the visitor centre as a 'destination'.

An ideal location for the visitor centre is the Kaituna Quarry. It provides a location where the land and lake intersect, offers a scenic vista across the lake to the Alps, has easy access via SH75, has sites of historic interest, provides a connection with the rail trail and is public conservation land.

Education and interpretation

In addition to the visitor centre, and irrespective of whether it is built, the rich Maori and Pakeha history and values of the lake warrant 'story-telling' via on-site interpretation (interpretation panels, etc). Interpretation plans are already under development and should be encouraged.

In contrast with inland alpine lakes, Te Waihora/Lake Ellesmere is not a 'scenic' attraction, although the vista across the lake to the Alps is spectacular, especially on sunset. Its 'pull factor' is educational - public understanding of the lake's outstanding natural and cultural heritage. On-site interpretation is a key means to achieve this educational role.

Off-site information is also required, to alert people to lake-related recreation opportunities. A 'one-stop shop' lake visitor website would be ideal.

The potential exists for a Maori eco-tourism venture based around interpreting relevant 'stories' (such as mahinga kai). However, recent research by Landcare Research (Wilson *et al.* 2006) does not suggest a positive outcome from this opportunity. The study examined potential interest in Maori eco-tourism products in the nearby Banks Peninsula area, by surveying international and domestic tourists[23]. They found that:

- Tourists wish to experience Maori culture in recognisable ways, which often means engaging with the traditional marketed aspects of culture rather than with contemporary culture
- Maori cultural components appear to add some value to the visitor experience and there was value in engagement on a personal level with Maori culture
- There is no real Maori cultural tourism ;market in the South Island, but there is potential to capture those international tourists who choose the South Island as their gateway or who never intend visiting the North Island
- The inclusion of Maori culture in tourism experiences did not appeal to most domestic visitors.

Bird-watching

Globally, bird-watching is a popular pursuit, attracting a dedicated cadre of participants who are willing to travel internationally to observe birds. The lake is an (inter)nationally significant bird site and already attracts international 'birders'. This opportunity could be developed further. This would require access to good viewing areas. Few facilities are needed, beyond those required to facilitate access, both on-site and off-site, such as web-based information. The potential market is birders, the public and eco tourism operators.

There is the potential to make the lake an outstanding bird-watching location on an international scale. A booming bird-watching 'industry' could support tourism operations such as guided tours and accommodation.

Lake cycle route

The success of the Little River Rail Trail suggests the potential to extend the route around the lake, or part of the lake. A circular route could extend from the rail trail at Birdlings Flat, along the public road that traverses Kaitorete Spit, across Ngāi Tahu land near the lake outlet and back along existing roads or embankments to complete the full circuit. Potential issues with the full circuit include:

- Requires the ability to cross the Lake outlet reliably. This could be overcome via web-based information provision about Lake opening times
- May not be of interest to cyclists given the mix of sealed roads and unsealed roads (i.e. riding mountain bikes on a sealed road is not attractive)
- Some stretches are long and straight (potentially boring)
- Some areas would require walking (e.g. end of Spit).

A partial route could be facilitated around the north east portion of the lake, from the existing rail trail, along the embankments to the Halswell Canal. With bridges, the route could be extended westward. As with the existing rail trail, walkers would be able to use the same trail.

Opportunities for commercial services exist if a critical mass of cyclists was concentrated in the area (in connection with the existing rail trail). This might include hospitality (food/drink provision); guiding; mechanical assistance.

Kayaking

Lake tributaries provide an ideal flat-water kayaking setting, however many areas currently lack aesthetic appeal. Riparian planting and improved water quality would enhance the setting for kayakers, especially on the Lower Selwyn, LII and the Halswell riv-

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[23] Tourist interest in three product scenarios was surveyed: A one-day guided boat trip (on the sea), a half-day guided walk (of Peninsula food trails) and an evening cultural performance and hang;

ers. This opportunity would suit most kayaker abilities, including family recreation. It would provide a convenient training area for local competitive kayakers who live or work in the area. Off-site information about get-in and get-out places would be required, along with on-site signage (similar to the Fish & Game New Zealand access system).

TABLE 5. **Recreation vision, outcomes and performance indicators for recreation.**

Recreation vision: A healthy recreation resource that is well used and valued

Outcome	Performance indicator
Lake-related recreation opportunities are recognised and valued by the public	Number of 'hits' for the lake on recreation/ tourism web pages
Visitors and local residents obtain a high quality recreation experience	High level of satisfaction with recreation participation. Measured via on-site and off-site surveys
Recreational impacts are minimised	1. Low level of visitor annoyance with other users.
	2. Minimal disturbance to sensitive cultural and environmental sites. Measured via visitor survey and direct contact with management agencies

9.5 Recreation vision, outcomes and indicators

A vision statement for lake-related recreation is proposed as: A healthy recreation resource that is well used and valued. The reference to 'health' refers to the natural environment base on which Lake-related recreation depends.

There are two keys to the realisation of this vision. First, is to enhance the resource so it better caters for existing uses - activity-based pursuits and land-based activities. This largely rests upon improving the quality of the natural environment, upon which existing use relies. This includes fish and wildlife habitat.

Second, is to unlock the potential for more people to connect with the lake via recreation. To achieve this, people need to identify the lake as a recreational destination. They need to know about it and have an identifiable destination(s) - where to go and what to do. This report suggests one 'solution' to this challenge - a lakeside visitor centre. This would become the visitor hub for the lake-see Section 9.4: Lake visitor centre.

Table 5 presents three long-term outcomes sought for lake-related recreation, and indicators that would reflect progress toward those outcomes (a monitoring programme).

9.6 Recommendations

Managers can implement the following actions to enhance Lake-related recreation opportunities:

- Construct a lakeside visitor centre
- Provide an information package about the lake: 'One-stop shop' web-based information site emphasising lake values and what people can see and do
- Enhance on-site interpretation
- Consider recreational needs when defining the lake opening regime
- Improve water quality
- Enhance riparian areas on lower reaches of key tributaries
- Maintain (and improve) public access to the lake
- Tidy up and actively manage land-based activity areas (Lakeside Domain, Coes Ford)
- Develop a recreation monitoring system.

9.7 Acknowledgements

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9.9 Appendices

Appendix A List of key informants

- Jason Arnold, Te Rūnanga o Ngāi Tahu
- Fiona Musson, Te Taumutu Rūnanga
- Ross Millichamp, Fish & Game New Zealand
- Steve Terry, Fish & Game New Zealand
- Dave Milward, Department of Conservation
- Poma Palmer, Department of Conservation
- Wayne Beggs, Department of Conservation
- Don Jellyman, NIWA
- Nick Allen, Ornithological Society of New Zealand
- Mike Peters, New Zealand Ecological Restoration Network
- Chrissie Gargett, Ellesmere Aquatic Club
- Phil Kiesanowski, New Zealand Jet Boat Association
- Russell Matheson, Canterbury Windsports Association
- Graeme Gordon, Canterbreeze Blokart Club
- Committee member, Canterbury Jet Sports Club
- James McGillivray, Eastcoast Boardriding Co.
- Mike Gopperth, Mike's Fishing Shop
- David Bailey, local resident
- Vince Burke, local resident
- Jill Crossland, local resident
- Colin Hill, local resident
- Ray Smith, local resident
- Geoff Spearpoint, local resident


SHELLEY McMURTRIE

10

ECONOMIC values

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This paper describes some economic values associated with Te Waihora/Lake Ellesmere including agriculture, commercial fishing, recreation and mahinga kai. In each case it gives a descriptive or quantitative value of the resource, any known changes in these values over the last decade, and considers the impacts on these values of proposed changes to the management of the lake and inflowing waterways. Commercial fishing output is worth $640,000 per year, and lake-associated quota is worth $3.3 million. The impact on these values of a conservation regime is not known. Farming production around the lake is worth $34 million per year. A proposed conservation regime with higher average water levels could reduce net farming benefits by $0.8 million per year with a Net Present Value of $14 million. These figures are very approximate. There is little information on recreational values. Recreational fishing values have declined with the quality of the fishery from an estimated $2.0 million per year in 1978/79 to $150,000 per year in 2003. There are very little data on lake values to tangata whenua, but the enormous effort and considerable expense they have incurred in trying to protect the lake implies very high values. Completing fences to exclude stock from the major stems of waterways feeding the lake would cost $0.75 million, while fencing drainage ditches would double this cost. Diverting water from irrigation to increase the flows in rivers and streams in perpetuity would have an opportunity cost of $8-12 million per cumec. An extra 1.5 cumecs of flow is required to maintain minimum flows in all tributaries even in a dry year.

10.1 Introduction

This paper addresses the economic values associated with Te Waihora/Lake Ellesmere, and in doing so:

- Describes the existing management regime of the lake including who pays, what the pattern of openings is and what the management issues are.
- Describes the economic values which are currently generated by the lake. The primary commercial value relates to fisheries, but there are also the wider cultural values associated with mahinga kai[1], recreational activity (including fishing, shooting and water sports), and conservation values over and above these.
- Describes the current value of lake-edge farming. This was originally defined as the drainage district, but this is extremely broad and covers an area of many thousands of ha, most of which is little affected by management of Te Waihora/Lake Ellesmere, and will be flooded only when it proves impossible to open the lake in spite of it having exceeded its trigger level because of countervailing sea conditions. We have modified this original area to look only at productive values of land which is below 4.6 m above mean sea level. This height is rather arbitrary, but was selected in earlier work as being the level below which land is sometimes affected by lake-related flooding. For the purposes of measuring farm production we included that area of land bounded by the sealed roads around the lake.
- Considers what other economic values could be generated by using the lake either in its current state or in an altered state.
- Assesses the impact on these economic values of changing the lake management regime.

10.2 Background

Te Waihora/Lake Ellesmere is a lake which some consider has undergone considerable degradation in recent decades. Various options are being put forward to improve the quality of the lake and its tributaries, and in this report we discuss the financial and also the non-market values associated with some of these changes.

We have looked at four principal areas including agriculture, commercial fishing, recreation and mahinga kai. In each case we have tried to establish the current value, either in a descriptive or commercial form, of the resource, any known changes in these values over the last decade, and the impacts on these values of the proposed changes to the management of the lake and inflowing waterways.

10.3 Management regime

This section outlines the current opening regime and who pays for the opening.

Opening Regime

The National Water Conservation (Lake Ellesmere) Order 1990 restricts consents for openings and closings being issued other than:

- To allow the lake to be artificially opened if the height exceeds 1.05 m a.m.s.l. in the period August-March or 1.13 m a.m.s.l. in the period April-July
- To allow the lake to be artificially opened any time from 15 Sept-15 October
- To allow the lake to be artificially closed when the level is below 0.6 m a.m.s.l.

In terms of practicality, the lake cannot be successfully opened if the level is not high enough (there is insufficient hydraulic head to scour the channel) or if weather conditions are not appropriate (the sea can close the channel almost immediately).

Currently a group, comprising representatives of Ngāi Tahu, Fish & Game, DOC, ratepayers and lake fishermen is contacted by Environment Canterbury (ECan) when the lake meets its trigger levels to decide whether it should be opened under the terms of a five year consent which was granted in 2006, and allows openings at the heights specified by the Water Conservation Order. To date the lake has never been artificially closed.

Costs of opening and allocation of costs

At present the costs of opening the lake are paid for as follows:

- 15 % the wider community in the ECan area through a general rate;
- 15% the wider community through a Selwyn District works and services rate; and
- 70% the landowners within the Te Waihora/Lake Ellesmere Rating District.

The landowners pay a variable rate levied on capital value according to the capital value of the land and its height above mean lake level (Figure 1). The areas within various contours, and the rates on capital are shown in Table 2. The relative rates were set in 1959. They represent the assessed relative benefits going to varying classes of land, and an assumption that benefit is related to capital value. As can be seen from the Rate Levied ($ / $100,000 of capital value) columns in Table 1, land of a given value in Class A is deemed to receive almost twice the benefits from lake opening of an equivalent valued piece of land in Class C, and 15 times the benefit to land of an equivalent value in Class E.

The annual costs of the lake openings from 2000-2007 averaged $164,000, but this is believed to be considerably less than the long-term average cost. The current rate on landowners in the Te Waihora/Lake Ellesmere rating districts totals $101,000, which is less than their share of the expected long-term average cost. It has been held at this

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[1] Mahinga kai refers to traditional food gathering species and associated resources, places and practices and can therefore include all the values associated with the lake including all the forms of food, plants, birdsand insects that are related to the major food gathering species and resources.

TABLE 1. **Te Waihora/Lake Ellesmere rating area contributing to lake openings.**

Land Height Range (metres above mean sea level)	Rating			Area (Ha)	Location
	Class	Rate Levied*			
		ChCh	SDC		
< 1.98 m (a)	A	130	98	6,245	Low, adjacent to lake and regularly flooded
< 1.98 m (b)	B	108	82	727	Low, away from lake margin, flooded at high lake levels or with wind surge
1.98 – 2.74 m	C	69	53	4,175	
> 2.74 (up to 4.57 m in parts)	D	17	-}		
> 2.74 (up to 4.57 m in parts)	E	9	7	}2,894	
Total Rating Area				**14,041**	

* $ / $100,000 of capital value

TABLE 2. **Cost per ha in various areas (2004 rating values).**

Land height range (metres above mean sea level)	Rating Class	Area (ha)	CapitalValue	Value / ha	Total Rate (2006–07)	Rate per ha / yr
< 1.98 m (a)	A	6,245	$34 m	$5,000	$35,000	$ 5.63
< 1.98 m (b)	B	727	$13 m	$18,000	$11,000	$15.40
1.98–2.74 m	C	4,175	$91 m	$22,000	$49,000	$11.75
> 2.74	D&E	2,894	$82 m	$28,000	$6,000	$ 2.03
Total Rating Area		**14,041**	**$220 m**	**$16,000**	**$101,000**	**$ 7.21**

Note: Capital value is value of land plus buildings.

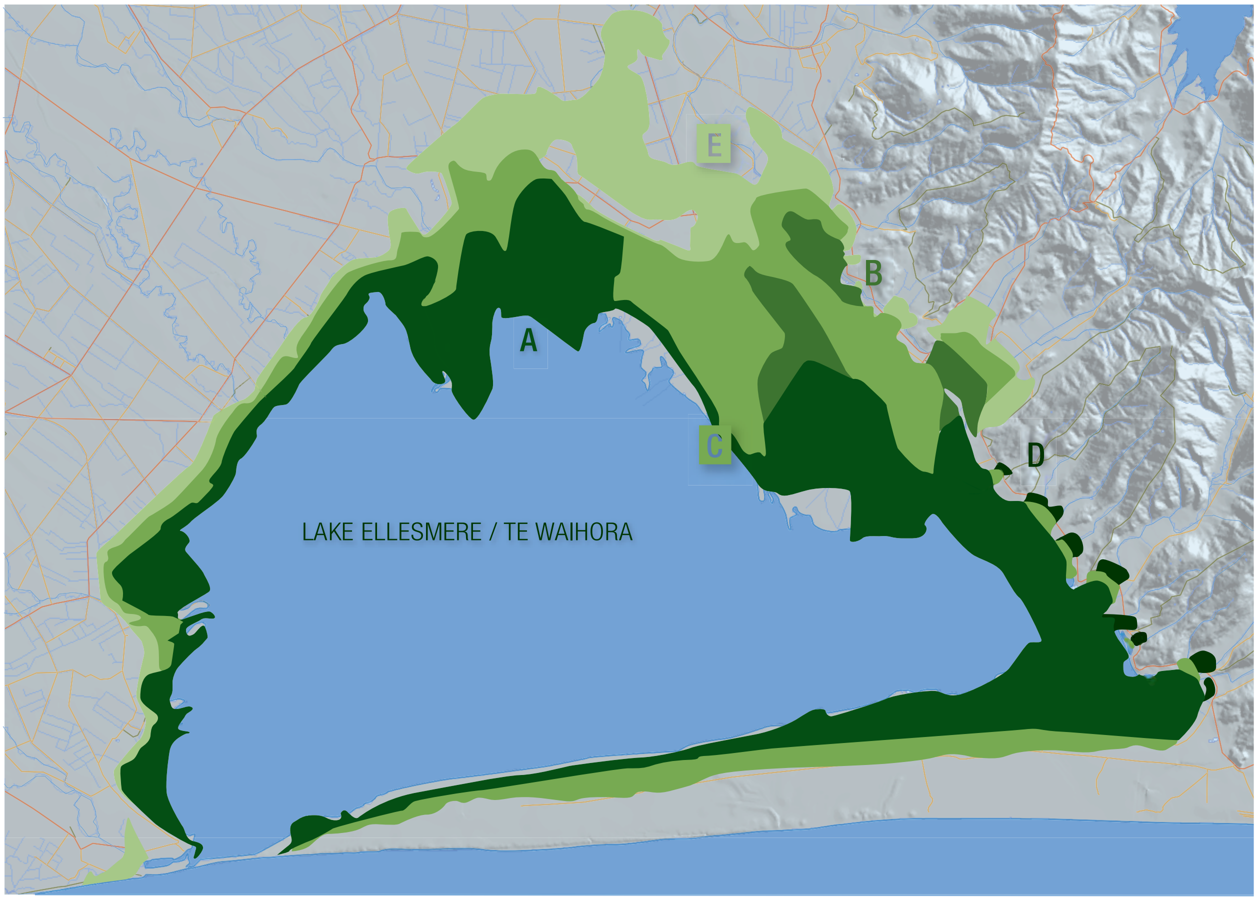

FIGURE 1. Land in the Te Waihora/Lake Ellesmere rating area. Refer to Table 1 and 2 for further information regarding the rating areas. Base Map sourced from ECan.

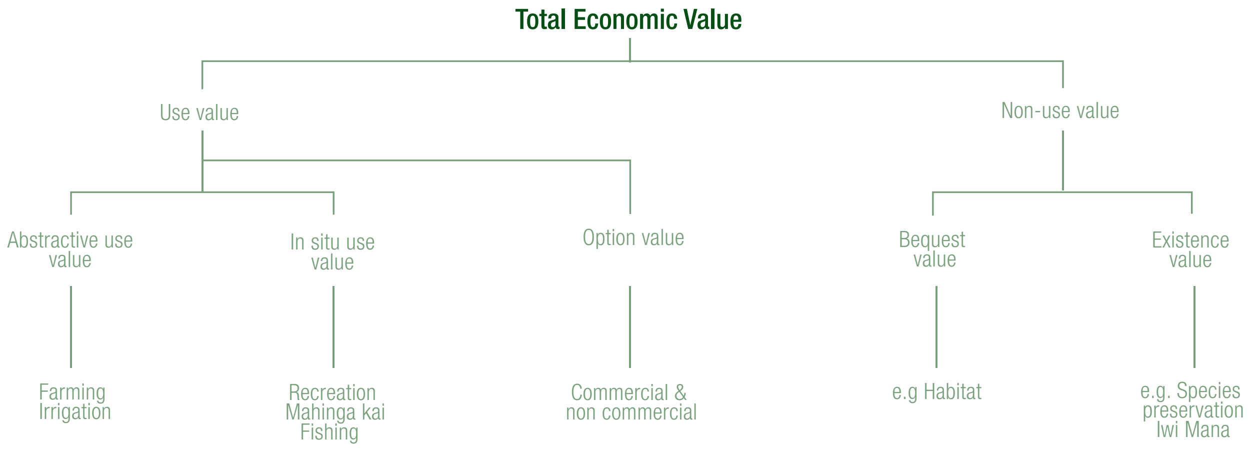

FIGURE 2. The Components of Economic Value[2].

low level because a series of years with low opening costs has led to a substantial buffer fund being built up. Once the buffer fund is run down (e.g. from a series of high-cost years), rates will return to their expected long-run average. Current rates are equivalent to $7.20 / ha / yr for land in the Te Waihora/Lake Ellesmere rating district. The rates per ha per year range from $2 on the high land which is little affected by floods, to $11.75 on the mid height land which has good soils and is moderately affected by flooding, to $15.40 on the low land which is of higher quality but some distance from the lake, to $5.63 on low land which is close to the lake but is of poor quality and hence does not benefit as much from flood protection as does higher quality land.

Management issues related to opening

The issues have not substantively changed in many years. There are multiple and competing objectives. Farmers want low lake levels to provide additional grazing, reduced flooding and make land subject to high water tables easier to work; fishermen want lake openings at appropriate times to allow recruitment of eels and flounders; tangata whenua want higher water levels to improve fishing and other aspects of mahinga kai; and, DOC wants a range of levels to provide the best habitat for different guilds (groups) of birds and to reduce grazing pressure where this will lead to re-establishment of indigenous vegetation.

10.4 Economic values

This section describes the framework for economic value analysis (see Figure 2 above). The major commercial use values are associated with agriculture and fishing, although there is also a very small amount of commercial recreation. Data for these values have been gathered from those involved in these activities. Non-commercial use values relate to water sports, angling, hunting and mahinga kai. Earlier studies provide information on values per recreational visit at other sites, and where possible these have been combined with information on current and potential recreational use of the lake to give an indication of the scale of recreational values associated with the lake. Mahinga kai is identified as a source of large, but non-quantifiable, value.

Non-use values include those typically ascribed to habitat, and knowledge of the existence of things which are not used. Te Waihora/Lake Ellesmere has a particularly large non-use value to Maori, who derive mana from the existence of this source of mahinga kai. The non-use value is believed to be far in excess of the pure use value derived from exercising their traditional rights to the lake.

Subsequent sections describe what is known about values for each of these aspects.

10.5 Commercial fisheries

Employment

The commercial fishing activity has declined steadily to the point where there are now only 5 somewhat-less-than-fulltime jobs and three part-time jobs associated with the fishery, or about five to six full time equivalent jobs in total.

The fish are processed in factories in both Selwyn District and in Christchurch, and some of the eels are exported live. Fish from Te Waihora/Lake Ellesmere are a significant part of the activity of at least one of these plants.

Previous work (e.g. on mussel farming) and regional economic models suggest that the total regional employment impact of fishing, after taking into account processing and all multiplier effects of both fish catching and processing, is anything from 4-10 times the direct employment in fishing. Hence the fishery probably supports the equivalent of at least 25 Full Time equivalent jobs in the region.

Value of species caught

The principal species caught are eels, yellow-eyed mullet and flounders (Table 3).

Eels

The current quota for eels is 121 tonnes. Between 90 and 100 % of quota is caught

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[2] Based on a framework provided by Dr G Kerr, Lincoln University (pers. comm.).

TABLE 3. **Summary of commercial fishing values by species.**

	Quota (tonnes)	Catch (Tonnes / yr)	Catch Value ($ / yr)	Quota Lease Value (ACE) ($ / yr)	Value of Quota $
Eels	122 (lake)	122	430,000	$120,000	$2,800,000
Flounders		135	200,000	$20,000	$430,000
Mullet		5	6,500	$1,300	$30,000

TABLE 4. **Agricultural production within the sealed road boundary area (very approximate values).**

Land Use	Area (ha)	Gross Farm Income ($ / ha / yr)	Gross Farm Income ($m / year)
Sheep, beef, deer & grazing - high productivity*	6,000	2,000	12.0
Sheep, beef, deer & grazing - low productivity*	4,147	300	1.2
Dairy	2,588	5,000	12.9
Arable	945	2,500	2.4
Poultry, pigs, bees, other , new farming	127	10,000	1.3
Fruit & Vegetables	164	15,000	2.5
Racehorses & grazing	110	10,000	1.1
Lifestyle	137	2,000	0.3
Forestry	31	1,000	0.1
Total	**14,250**		**34**

Sources: Areas from ECan interrogation of Agribase data; $ per ha from farmers and farm advisers for sheep, beef, dairy and arable. Other figures are extreme approximations.

each year, and its approximate landed value is $430,000 / yr. The current market value of Annual Catch Entitlement (ACE) is believed to be of the order of $120,000 per year, and this represents the pure profit (i.e. the value over and above costs) arising from the eel fishery. The difference of $310,000 / year represents the returns to fishing itself, and has to cover the costs of fishing equipment, operating costs and labour.

The market value of Quota is about $23,000 per tonne. Hence the total value of the quota is $2.8 million. This value represents the current value of the stream of future pure profits arising from the eel fishery.

Flounders

The annual catch of flounders from Te Waihora/Lake Ellesmere varies enormously from year to year, and in the last decade has ranged from 3-143 tonnes with an average yield of 78 tonnes per year. The preceding decade (1986-95) was much the same, and the decade 1976-85 had a range of 20-285 tonnes per year and an average of 135 tonnes per year. At an average landed price of $2.60 / kg (including imputed ACE costs), this fishery has an annual value of $200,000. The pure economic surplus (i.e. revenue after deducting all costs including labour) is estimated to be about $20,000 per year, and the total Quota Value for the average 78 tonnes of flat fish caught on the lake is believed to be around $430,000.

Fish take about two years from entering the lake to reach maturity, and the catch is believed to be strongly dependent on the lake being open in the September-October period for recruitment of young fish. Notwithstanding that, statistical analysis reveals only weak correlation between the duration and timing of opening periods and the catch quantity.

Mullet

The current quota for mullet in Area 3 is 8 tonnes, and it is believed that the vast majority of these are caught in the lake. While data are not precise, it is believed that the annual catch is approximately 6.4 tonnes. This species is not particularly highly regarded by the market, and the market is quite small. The landed value ranges from $0.5-$3 / kg with an assumed average of $1 / kg. Hence the annual catch has a value of around $6,500. Quota (ACE) leases for about $0.20 / kg / year, and on this basis we estimate that the total value of the 6.4 tonnes of quota caught in the lake is of the order of $30,000.

10.6 Agriculture

Production values

ECan has provided estimates of areas in each type of farming use around the lake. We have discussed with several farmers their typical production per ha on land strongly affected by the lake level, and have used this to estimate production values / ha for this land, while for other farm land we have used more typical estimates of production per Ha/ha[3]. We have multiplied together the areas and the production / ha to get total production values for farming in the area bounded by the sealed roads around the lake (see attached map). The agricultural production from this 14,250 ha[4] (Table 4) is estimated to be very approximately $34 million per year, but the error margin is at least 20 per cent. Almost 40 per cent of the income is from dairying.

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[3] Pers. comm.. S Ford. Agricultural Economist. Average figures for good quality irrigated and dryland farming have been used.

[4] This is approximately the same area as the Lake Ellesmere Rating District, although the boundaries differ slightly with the rating map including an area of less affected land, almost all of which is above the 2748 m contour.

While the figures are highly approximate, changing assumptions about incomes per ha or the areas of grazing which are high productivity or low productivity is unlikely to shift the result outside the range $25-45 million per year.

Effects of the lake on farm production

It is not possible to accurately quantify the effects of the lake on agricultural production. Areas closest to the lake are obviously the most severely affected (Table 5), and this is recognized by the way in which lake openings are funded. As described earlier, worse affected land is charged a higher rate per $ of capital value, but the most affected land tends to be of much lower value per ha because of the risk of flooding and the effects of flooding on the soils.

Production values at risk

Land use and survey maps can be combined with the rating maps to show which land uses are most severely affected by high lake levels and, more particularly, by any change to the management regime which increases lake opening levels. By multiplying the land use in ha by the estimated production value / ha we can estimate the value of production at risk between each contour (see Table 6).

Impacts of changes to lake management

At present the lake is (generally) opened at water levels above 1.05 m during the period August-March, and above 1.13 m in the period April-July. Suggestions have been made that the opening level could be increased, or that the lake could be held at higher levels for longer periods. It is the latter of these two that is examined as part of the "Conservation Strategy" outlined in Hughey *et al.* (2009).

The greatest impacts on production of a higher average lake level will be on land which is at present often dry but is regularly flooded. It is likely that the loss of production on land below 0.76 m is minor because it has limited grazing value even when dry. The 1,672 ha of land between 0.76 and 1.0 m will be significantly affected. Less than 50 ha of the land described as being used for dairy farming and 65 ha of the land used for arable farming is in this range, although in both cases the land is part of a larger farm and probably none of the land in this height range is actually used for those purposes. Production is primarily sheep and beef, and production values are believed to average less than $130 / ha / year[5]. Hence if this land became unusable for farming, the direct loss of production would be of the order of $230,000 / year.

Most farmers with low contour land manage that as part of a larger farm. They will have additional losses because they will have to change their management practices and will be unable to manage their properties as effectively as before. One farmer suggested that losing this low level land could reduce gross income by perhaps $500 / ha / year of low land. The losses due to required management changes could raise the potential losses on all the land < 1.0 m to perhaps $300,000 / year if the average lake level was sufficiently raised so as to make land below 1.0 effectively useless for farming. At a 5 % discount rate[6], this $300,000 has a Net Present Value of $5 million.

There will be more significant direct production effects on the 4,072 ha of land in the range 1.0-1.7m. There is approximately 650 ha of dairying land in this range and 70 ha of arable land, with the other 3,350 ha being sheep and beef or straight sheep farming, with one deer farm. The loss of this land to agriculture would lead to a direct loss of production of the order of perhaps $3,000 / ha / year for dairying and $500 / year for grazing (significantly less than average because the soils and pastures are of less than average quality). On this basis, the value of production at risk in this area is around

Photo **Sheep and beef farming are the major component of the $17 million of farm production at risk from flooding.** Photography **Shutterstock.**

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[5] Discussion with two farmers with significant land in the area below the 1.5 m mark revealed average incomes (including their higher land) of the order of $150 / ha, implying a significantly lower figure on the low land.

[6] Analysis of public sector projects typically uses discount rates of 10 % with sensitivity testing of 7.5%. This is justified on the grounds that this approximates the opportunity cost of capital. Research into agriculture has estimated the typical long-run returns to capital to be of the order of 3-5%, and for this reason a 5 per cent discount rate has been used here.

TABLE 5. **Relative drainage charges / $ capital value and / ha in various areas (2004 rating values).**

Height Range	Rating Class	Area (ha)	Relative Flood Impact	Rate Charge ($000/yr)	Proportion of total Drainage rate
< 1.98 m (a)	A	6,245	30	35	35
< 1.98 m (b)	B	727		11	11
1.98 – 2.74 m	C	4,175		49	48
> 2.74	D}	2,894		} 6	} 6
	E}			}--	}--
Total Rating Area		**14,041**		**101**	**100**

TABLE 6. **Land Use and Production Values in each height band.**

Zone (metres above mean sea level)	Land Use (ha)					Production at Risk	
	Sheep /Beef /Deer	Dairy	Arable	Other	Total	($m / yr)	NPV ($m)*
< 0.3						Trivial	< 0.1 m
0.3 – 0.76						Minor	< $0.5 m
0.76 – 1.0	1,672	0	0	0	1,672	$0.3m	$ 5 m
1.0 - 1.70	3,350	650	70	0	4,072	$3.7m	$ 63 m
1.7 – 2.74	3,424	900	70	150	4,521	$13m	$223 m

*Assumes 5 % discount rate

$3.7 million / year, with a net present value of $63 million. The lowest land in this band probably has significantly less productive value than does the higher land.

The next band of land is the 4,521 ha from 1.7 m-2.74 m, which includes a further 900 ha of dairying ($5,000 / ha), 70 ha of arable and 150 ha of other production such as pigs, fruit and vegetables and lifestyle blocks. The balance of 3,420 ha is grazed ($2,000 / ha). On this basis the production at risk in this area is $13 million / year, and a net present value of $223 million. The lowest land in this band probably has significantly less productive value than does the higher land. A raised lake level will lead to some direct loss of production through land being flooded more frequently[7] and some loss of production through a higher water table making the land more difficult to work.

Higher land further back from the lake will be less affected by the high water table, but the effects can be felt for a very considerable distance back from the lake. It is not possible to put a value either on the area of land so affected, or the loss of value / ha.

Benefits at risk

Production is not an estimate of net benefits[8], because production requires the use of expensive inputs and labour. The benefits also accrue over successive years into the future. One way of estimating the net present value (NPV) of the stream of future benefits is to consider the value of the land.

Low level land has been valued, on the basis of recent open-market purchases and exchanges of lake-front land by DOC, at around $700 / ha. If we use this as the basis of lost agricultural benefits, then the loss of 1,672 ha of land between 0.75 and 1.0 m reduces benefits by $1.2 million (NPV). Even if we add in the 2,600 ha between 0.3-0.75 m at a value of $1.8 m, we still have a total of under $3 million. On this basis, it seems likely that our earlier estimate of $0.3 million / year of lost agricultural production, with a NPV of $5 million significantly overstates lost agricultural benefit.

Land and buildings in the next highest block of land (1.0-1.7 m) had an estimated 2004 rateable capital value of $33 million[9], which is again significantly less than the $44 million NPV of lost agricultural production. Land and buildings in the range 1.7-2.7 m had a capital value in 2004 estimated to be $105 million, which again is far less than the $223 million NPV of lost production.

Estimate of agricultural costs under conservation regime

The "Conservation" regime outlined in the Hughey *et al.* (2009) would involve higher average water levels, but no increase in levels at which the lake is opened. It would also involve fencing stock out of all waterways. It would permit "conservation" grazing around the lake edge, which is taken to mean "grazing that enhances conservation values and is done without regard to any loss of agricultural production". Finally, the conservation regime could involve higher stream flows. Both fencing costs and higher stream flows are considered in section 8 of this report.

We assume that for practical purposes the conservation regime would lead to the loss of all grazing on land below 1.0 m, and the loss of half the production on land from 1.0-1.2 m. We assume that a rise in average

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[7] Even if the nominal lake level is below 1.7 m.

[8] Benefits can perhaps be best thought of as net profits after all expenses.

[9] The 2004 rateable capital value of all land below 1.98 m is $47 million. If land below 1.0 m is worth $1.2 million, then the land from 1.0-1.98 m is worth $46 million and the pro-rata share of the land from 1.0-1.7 m is $33 million.

Photo ***Fencing main stems of major streams to exclude stock would significantly improve water conservation values at a cost of only $0.75 million.***
Photography ***Colin Hill.***

TABLE 7. **Potential loss of production and benefits from changes to the lake management regime.**

Zone (m a.m.s.l.)	Production at Risk		Benefit at Risk based on capital value	Potential Loss Under Conservation Management Regime (N.B. large error margin)				
	($m / yr)	NPV * ($m)	$m NPV	% loss	Production		Benefit	
					$m/year	$m NPV	$m/year	$m NPV
NPV								
< 0.3	Trivial	< 0.1	0.1	100	<0.1	0.1		0.1
0.3 – 0.76	Minor	< 0.1	0.1	100	<0.1	0.1		0.1
0.76 – 1.0	0.3	5	1.0	100	0.3	5.2		1.0
1.0 - 1.2	1	12	9	50	0.4	6.0		4.6
1.2 - 1.7	3	52	23	15	0.5	7.7		3.5
1.7 – 2.74	13	224	105	5	0.7	11.2		5.2
Total	**17**	**290**	**138**		**1.8**	**30**	**0.8**	**14**

*Assumes 5 % discount rate

ground water levels could reduce farming production by around 15 % in the 1.2-1.7 m range. The total value of this loss of production could be about $1.8 million / yr or a Net Present Value of $30 million (Table 7). The savings in farm production expenses in the long term mean that the loss of benefits could be around $0.8 million per year with a Net Present Value of $14 million. We emphasise that these are preliminary estimates, which have as their objective the development of an analytical framework and to get some preliminary idea of the likely scale of costs. Considerably more work is needed to verify some of these figures.

We also emphasise that these figures do not equate to the current costs of flooding, but rather to the changes in costs that could arise from the implementation of a conservation regime.

10.7 Recreational values

Recreational benefits for fishing have been assessed in several New Zealand studies. These suggest an average value per fisher-day of $36. The information on other recreation is more limited, but suggests average figures of around $21 per day.

Little information on the number of current recreational uses is available (see also Booth 2009). Power-boating and water skiing have reportedly declined (presumably with the availability of alternative venues such as Lake Hood), but the completion of a section of the Little River Rail Trail has increased recreation, albeit recreation which is much less intimately connected with the lake (Table 8).

10.8 Tangata Whenua values

Ngāi Tahu values associated with the lake include its role in providing mahinga kai, its spiritual significance as a taonga held on behalf of both Ngāi Tahu and the wider community, and the importance of a healthy lake as a source of mana to the iwi.

These values are very significant, but are not quantifiable in financial terms. The significance of the values to Ngāi Tahu are evidenced by:

- The enormous efforts they have made over many years to regain tino rangatiratanga over the mahinga kai
- Their work to include the lake in the Treaty Settlement

- Their work with DOC in developing the Joint Management Plan for the lake
- Their on-going involvement in efforts to improve lake management
- Their research input into understanding the cultural health of the lake.

The only quantitative data available are that the iwi take fish with a market value from $5,000-$30,000 depending on the year (and the accuracy of the data). However, as with recreational fishing, the values associated with gathering the fish may be much greater than their market value.

One source suggests that perhaps somewhere between 50 and 150 members of the iwi use Te Waihora/Lake Ellesmere for mahinga kai, but this is very much a guestimate because formal records have not recently been kept (see Table 9).

10.9 Other values affected by lake management regimes

Changes to the way in which Te Waihora/ Lake Ellesmere is managed are expected to involve both costs and benefits. Costs are likely to be incurred by upstream users. They could include reduced irrigation (to increase instream flows) and fencing costs.

Fencing

Fencing costs vary according to whether they are designed to contain sheep or cattle. Advice from ECan suggests that average fencing costs are likely to be about $3,600 / km. The length of fencing required varies depending on the level of improvement required, and whether the objective is to remove stock from rivers, creeks, drainage ditches or ephemeral streams. We also note that fencing will on the one hand make access for cleaning drains more difficult and on the other is likely to increase the shading in the ditches and hence reduce the growth of weed in the drains and so reduce the frequency of cleaning required.

A review of the major streams is currently being undertaken by ECan. This work will not be finished for some time. However, we have undertaken an initial assessment of the extent of fencing required on the basis of catchments for which reasonable data are available. We estimate that approximately 215 km of fencing would be required on the main stems of the major streams[10] to exclude stock and significantly improve the water conservation values. The cost of this fencing would be around $0.75 million. Fencing of major and minor drainage ditches could double this length and cost.

Higher water flows and effects on irrigation values

The estimate of Opportunity Cost in this section compares the value of water instream with its potential value in irrigation. However, this is not necessarily the trade-off that needs to be made, certainly at present. There is strong evidence that many existing irrigators could reduce their use of irrigation water by applying the water more efficiently. This reduced water could be applied at little cost in terms of lost production, and possibly at little financial cost, or even a financial saving, in terms of abstracting and applying water. Hence improved flows in streams could potentially be obtained at little cost in terms of lost agricultural production.

In the long term, the increasing scarcity of water and an apparently insatiable desire for increased irrigation are likely to lead to water values at least as high as those discussed below. If there are further increases in the efficiency with which water can be used, this is likely to drive up the value of water still further than has been assumed in this analysis, although the prices currently being paid for shares in existing irrigation schemes are probably only affordable to farmers who use the water in ways that are efficient, at least by current standards. Current information suggests that water from Central Plains delivered to the gate could cost up to $7,000 / ha.

Opportunity cost

In principle one could estimate an economic cost of increasing water flows by estimating the reduction in irrigation abstraction required to obtain these flows. ECan[11] has calculated the reduction in abstraction required to maintain the flows at their minimum levels. For the 2005-06 irrigation season, when there was a “reasonable” (average?) summer demand on top of a very dry winter and hence a low water table, a very provisional estimate is that to maintain water flows and acceptable river flows would have required a reduction in all irrigation in the area between the Rakaia and the Selwyn by around 40% (apart from those in the Rakaia riparian strip, whose water depends almost entirely on flows in the Rakaia). This estimate is based on a number of assumptions, including that current water abstraction is 60% of permitted take[12].

One could also, in principle, model the amount of supplementary water required in each of the last 20-30 years rainfall conditions to maintain all spring-fed rivers and the Selwyn at minimum flows assuming all irrigation consents were exercised to the full (comparison of this flow with the actual or calculated flows at full irrigation). The supplementary water could be of the order of 1-1.5 cumecs. It is interesting to compare this with the costs of obtaining this much water from irrigation schemes such as the Opuha and Waimakariri (where consents are traded, presumably at marginal value), recalling that the irrigation rights give access to sources of water of varying reliability and that the market price reflects the value

TABLE 8. **Economic Values of recreational use of Te Waihora/Lake Ellesmere.**

Year	Angler Days	Value ($000 / year)
1978/79	55,800	2,008
1995	12,000	432
2002	4,000	144

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[10] Silverstream/Snakes/McGraths, Boggy Creek, Irwell, Harts Creek/Birdlings Brook/tributaries, Selwyn, LI & LII, Lower Halswell.

[11] Howard, (ECan) pers. comm. This estimate is based on a number of assumptions, including that current water abstraction is 60% of permitted take. We do not actually know whether this is true in any year, let alone a dry year.

[12] Reliable data on this percentage are not available for any year, let alone a dry year.

TABLE 9. **Approximate customary harvest (data supplied by Ngāi Tahu). Weights of fish assume average weights of 450 g and 1 kg for flounders and eels respectively.**

Year	Patiki (Flounders)		Tuna (eels)	
	Approx weight (kg)	Approximate market value ($)	Approx weight (kg)	Approximate Market value ($)
2003	540	1,400	1400	5,000
2004	990	2,600	800	2,800
2005	5130	13,500	4700	16,600
2006	1215	3,200	1700	6,000

to a farmer of having access to this water. Alternatively, we can consider the differences in land values for land which has water available compared to land that does not.

Irrigation schemes provide irrigation "shares", and one share typically provides around 6,000 m3 / ha over a season of variable length (240 days in the Waimakariri case). Two cumecs over that long an irrigation period is the equivalent of about 6,900 shares[13]. The current cost of shares plus an amount to cover operating costs into the future is about $4,000 / share[14]. Hence the cost of acquiring this water is about $25 million. It should also be noted that this water is not particularly reliable in the period January-April, and hence the value of a guaranteed flow is even higher than this.

An alternative assessment is based on the design criteria for an irrigation scheme, which typically proposed provides 0.6 l / sec / ha. Hence 1 cumec provides sufficient water to irrigate 1,700 ha. A report for the Ritso Society (from Creighton Anderson-valuers) suggests that land in Selwyn-Ashburton area with irrigation available is worth $5-6,000 / ha more than land without irrigation. Current information suggests that the Central Plains Water Scheme costs for water delivered could be as high as $7,000 / ha. Based on these figures, the net present value of increasing the long-term flow of water in rivers could be of the order of $8-12 million per additional cumec.

Fishing

Fish and Game North Canterbury has the objective of increasing the number of anglers using the lake and its tributaries by 1-2,000 per year. If each angler fishes 5-10 times / year and a fishing day has a value of $35, then the related value generated is in the range $175,000-$700,000 / year.

Other recreation

While other research suggests possible recreation values of $25 / day, there is no information available on the number of users or how these might change with the changes in lake management discussed by Hughey *et al.* (2008) in the Integration Report.

Mahinga kai and other Maori values

The changes in lake management discussed in Hughey *et al.* (2008) are expected to improve these values but, as described earlier in this report, it is not possible to put a financial value on these changes.

Environmental services

Examples of environmental services include provision of enhanced wetland for migratory birds. Again, it is not possible to put a value on these changes.

10.10 Conclusions

Accurate quantification of economic values associated with Te Waihora/lake Ellesmere is problematic. However, "broad brush" estimates can be made in relation to fishing and agriculture. The effects of a conservation-oriented lake management regime on fishing cannot be determined, but economic impacts on farming have been outlined. Higher average lake levels would reduce net farming benefits by 2-3%, while stock exclusion from all tributary inflows in the study are would have substantial "one-off" costs. Increasing tributary flows by foregoing irrigation abstraction would also have substantial opportunity costs.

Tangata whenua values are already high but are not easily quantified in economic terms.

There is clearly scope for research on the costs and benefits of change to lake management across a range of values. Calculation of "value shifts" would provide critical information to underpin the evaluation of intervention options.

10.11 References

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Hughey, K.F.D., Taylor, K.J.W. and Ward, J. 2009. Current state and future management. *In:* Hughey, K.F.D. and Taylor, K.J.W. (eds.). *Te Waihora/Lake Ellesmere: State of the Lake and Future Management.* EOS Ecology, Christchurch. Pp. 111-132.

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[13] Two m3/sec x 60secs/min x 60mins/hr x 24 hrs/day x 240 days/season = 41 x 106 cubic metres = 6,900 shares.

[14] Trading is quite limited, but reasonable parcels of shares have traded at $2,500-$3,500. Future annual operating costs of perhaps $100 / year have been converted to a single lump sum of $1,000.

SHIRLEY HAYWARD

11

CURRENT STATE and future management

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Te Waihora/Lake Ellesmere (NZ's 5th largest lake) is highly modified, is managed primarily to protect agricultural land on its margins, yet remains highly rated for a range of other values. These include high cultural importance to Ngāi Tahu, international wildlife values, nationally important native vegetation, and regional and local value for commercial fishing and recreation. Impacting these values are key drivers, few of which have linear cause and effect relationships, and most of which are human-induced. Given the lake's geography and the range of factors described above, it is best described as a complex system. Understanding complexity requires multiple and integrated ways of system conceptualisation. Such understanding can then be developed to take advantage of management opportunities. To these ends researchers updated knowledge about the state of the lake. Some indicators suggest a reasonable state of health, some show decline, and one indicates a part of the system (brown trout fishery) which has virtually collapsed. While the lake is probably in better health than scientists would have predicted prior to this research, there are caveats, and actions needed to prevent further decline and lead to overall improvements. A vision for the lake is thus proposed. It involves three scenarios and associated management actions, all evaluated against criteria to help decision-making and maintain system resilience. These scenarios are "improved status quo" management; a "realistic and resilient" environmental system; and an "idealised conservation based" system. The second scenario contains many desirable attributes, subject to community consultation for confirmation of desired outcomes, with achievable management actions. What we do not know with any certainty are the likely comparative costs and benefits associated with these interventions, nor some of the potential responses. Consequently we propose a learning-based approach in which management actions are implemented, indicators and system dynamics monitored and changes made as appropriate.

11.1 Introduction

Te Waihora/Lake Ellesmere is New Zealand's 5th largest (by area) lake—it is a brackish "bar lagoon" type lake of around 20,000 ha sitting at the foot of a largely agricultural catchment of 256 000 ha. The lake is important culturally[1] (Pauling and Arnold 2009), for its wildlife (Hughey and O'Donnell 2009, for its botanical features (Grove and Pompei 2009) and for its indigenous fisheries values (Jellyman and Smith 2009). While it retains recreational values (Booth 2009), in some areas these have been disastrously reduced (Millichamp 2009). Agriculture and commercial fishing are important activities (Butcher 2009) around and in the lake. The principal form of lake management is via a managed lake opening regime-this management is one of the influences on water quality (Hayward 2009) and in turn is influenced by water quantity changes (Williams 2009, Howard-Williams and Larned 2009, Thorpe 2008). All of these values and related influencing variables or factors combine and interact in complex and often non linear ways. Adding to this complexity are the multiple agencies with statutory planning and other responsibilities for the lake (Rennie 2007).

Given this range of interests, and concern about the future of the lake, it is our aim in this paper to:

- develop a framework to inform our understanding of the lake, its values and processes in a systematic way and to enable future management of the lake
- summarise values, drivers of change and indicators to identify trends and changes in the overall state of the lake. In doing so all findings are based on research evidence provided
- identify a range of scenarios for the lake and ranges of variables that would need to be managed/achieved to enable each of these scenarios.

In further developing this approach we held two day-long workshops with the principal researchers identified above. The workshops helped identify cross-discipline issues, assisted with the overall framework development, and clarified a range of matters. In addition, draft scenario material was provided to a stand-alone Te Waihora/Lake Ellesmere Statutory Agencies Group[2].

The 1996 report entitled 'The natural resources of Lake Ellesmere (Te Waihora) and its Catchment' (Taylor 1996) outlined the many values associated with the lake and issues for its management. Chapter 11 (Davis *et al.* 1996) of that report undertook an integrated and ecosystems approach to management of the lake, but stopped short of identifying desirable outcomes or recommending preferred management actions. Nevertheless the chapter remains an important contribution to thinking about the lake and the possibilities for its future management. Indeed, in many ways, it and

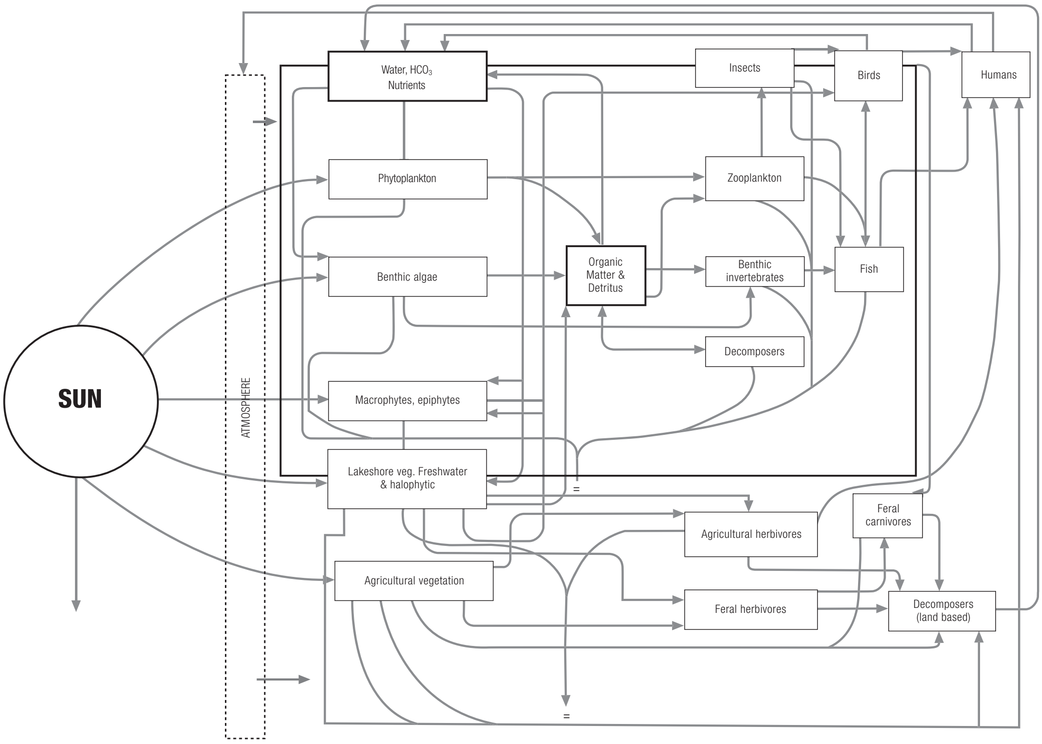

FIGURE 1. Model of the Te Waihora/Lake Ellesmere energy flows (adapted from Davis *et al.* 1996).

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[1] In this context 'cultural' refers primarily to the Nga Uara Ngāi Tahu/The Ngāi Tahu Values - from hereon therefore 'cultural' will mostly be referred to as The Ngāi Tahu Values.

[2] These are agencies with a formal statutory role regarding the lake: Ngāi Tahu, Environment Canterbury, Department of Conservation, Christchurch City Council, Selwyn District Council, Fish and Game North Canterbury and Ministry of Fisheries. Also in attendance was Ministry for the Environment.

a related research paper (Gough and Ward 1996) provide a foundation for thinking systematically and in integrated ways about future lake management. Some of this thinking is now more commonly referred to, and captured in notions of, soft systems application (e.g., Checkland 1981), adaptive management (e.g., Gunderson 1999, Holling 2001) and panarchy (Gunderson and Holling 2002).

The essence of all these approaches can be summarised as:

- the system needs to be modelled
- no system is ever in a fixed state and that there are cycles of use, renewal, storage, etc (see Figure 1)
- almost all model connections are non-linear
- different values sit in different contexts and react over often dramatically different scales of time and space
- there is uncertainty related to predicted responses to management intervention
- there is a need to define goals and resource attributes within ranges to take account of interaction effects, etc
- management needs to be flexible and responsive to new knowledge and to changing circumstances.

Gough and Ward (1996) noted with respect to the lake "...that the use of a "soft systems" learning approach to management would be of considerable benefit to present and future decision-makers and managers." Given all of the above we have attempted to develop an approach that implies sustainability requires maintenance of adaptive cycles across space and time within a biophysical system in which underlying relationships are recognised and understood. To make sense of this complexity we have undertaken the following approach

- defining the system model - this work starts with an adaptation of the 1996 ecosystem model (Davis *et al.* 1996: 162), identifying the key connections, and then uses the concept of adaptive cycles as a way to consider some of the key resources and their responses and interactions
- describing the overall state of Te Waihora/Lake Ellesmere
- identifying drivers of change to indicators/values
- suggesting desired futures for Te Waihora/Lake Ellesmere and management actions and their evaluation.

Finally, we draw some conclusions and promote overall recommendations designed to guide future management.

To achieve the above we have used the following process:

- A range of 'scientists' worked on individual values associated with the lake, from their disciplinary or 'value' perspective, i.e., cultural (Ngāi Tahu), wildlife, indigenous fisheries, vegetation, recreation, introduced fisheries, economic interests, water quality, water quantity. Each scientist was given a brief of work, essentially covering: an update where appropriate of the Taylor (1996) report, current state of the value, drivers and indicators of change, desired future outcomes and recommended management actions.
- The scientists were brought together at two 'integration' workshops where progress was discussed, outstanding issues raised and resolved, and ongoing work to help with this integration paper clarified.

A proposed framework for this paper was developed (incorporating ideas from others as well as the scientists) and shared with the scientists for comment. Having confirmed the approach outlined above, it has then been a matter of bringing this work together within the contexts of future management and reflection on the 1996 report.

Photo ***Some threatened plants are in gradual decline around the lake, but some isolated replanting programmes are at least helping to improve general biodiversity values.*** *Photography* ***Shelley McMurtrie.***

11.2 A systems approach to thinking about the complexity of relationships associated with the lake

Figure 1 is an ecosystem-based model of Te Waihora/Lake Ellesmere built around the energy flows and the food web for the lake and its environs. The model has been taken from Davis *et al.* (1996: 162) with some modifications; the main change is the inser-

Photo ***Weeds threaten native plant communities around the lake, and require active control, such as Fish and Game North Canterbury removing willow from around the lake margin.*** *Photography* ***Shelley McMurtrie.***

tion of an atmospheric link between the sun and primary producers to reflect increasing interest in climate change and the impact that is likely to have on the system, and other connections largely associated with agricultural interactions with the lake.

Although the model is a simplified one in that it only incorporates the major contributors, the energy flows and links to the food web do illustrate the complexity of the lake ecosystem. It indicates a large number of interactions between plant and animal groups, and implies levels of interdependency between these components; a change in the distribution or abundance of one has "flow-on" consequences for others.

However, such a view of the lake system has limitations. It does not, of itself, describe, let alone explain, the interactions between the biota and the physical and chemical environment of the lake, which are fundamental to the condition of the system. Moreover, the energy flow and food web model tells us nothing about the dynamics of the system (how the biological elements vary spatially or over various time cycles such as seasons), its stability (whether any of those elements are in long-term decline or increase), or its optimality. It may also imply linearity in cause and effect - but this is clearly often not the case. Optimisation is a particularly important consideration for sustainable lake management; do some aspects of the physico-chemical environment favour some parts of the biological system over others, or are conditions the best possible with respect to the biota as a whole? If the former, are those that are advantaged the ones with the highest values? And how will interventions affect those relativities? To try and help address some of these questions we have included an examination of many of the individual components of Figure 1 (see section 11.3) and key effects of changes to each of these. But, neither the energy systems model nor this tabular approach adequately deals with the complexity of this system.

To start to address these questions, the elements of the energy flow and food web model need to be coupled to our understanding of the way the plants and animals of the lake interact with their habitats. Because the lake is a complex system it is very useful to put these types of considerations in a wider systems context, and to recognise that the energy flows associated with the lake are part of, and are governed by a series of cyclic processes that take place across a range of scales, that are both spatial and temporal. These 'adaptive' cycles are central to the concepts of "soft" or adaptive management, and 'panarchy' mentioned above.

An adaptive cycle has four components:

- Exploitation-use or harvesting resources from a system
- Accumulation-storage of material and energy in the system
- Release-disturbance of the system
- Reorganisation-restructuring of the system after disturbance (Gunderson and Holling 2002).

Adaptive cycles can be identified or described with respect to both the physico-chemical and the biological parts of the lake system. For example, the main components of the adaptive cycles for water quality (physico-chemical), phytoplankton (biological) and for wading birds are given in Tables 1-3.

Each adaptive cycle continues as long as the system can recover from the degree of disturbance undergone. If not, maladaptive consequences can arise and the system is no longer sustainable. Sometimes such consequences of disturbance are immediate and obvious. For example, extensive canopies of submerged macrophytes were once a feature of the lake that had for many years fluctuated in response to environmental stresses. However, their disturbance as a consequence of the severe storm of April 1968 resulted in their long-term loss as a significant feature of the aquatic ecosystem (Gerbeaux and Ward 1991). On the other hand, lack of resilience in the system may take many years to manifest itself, so that disturbances, such as lake level manipulation for particular purposes, or stormwater inputs, may take many cycles before adverse impacts are observed.

Considerations of scale provide a funda-

TABLE 1. **Adaptive cycle for water quality in Te Waihora/Lake Ellesmere (Source: B.R. Jenkins, pers. comm.).**

Adaptive Cycle Component	Physical
Exploitation	Water quality impacts of land use and sea water inputs
Effects of human use and natural processes	added sediments, nutrients and bacteria
	overtopping with sea water
Accumulation	Retention of contaminants in lake and lake ecosystem
Lake as sink for the catchment	build-up of sediment, nutrients and bacterial levels
	nutrient uptake by plants
Release/disturbance	Flow through constructed cut
Lake openings	contaminants removal during lake discharge
	sea water incursion during lake opening
Reorganisation	Return to lake conditions
Channel closure	reduced sediment and nutrient concentrations
	increased salinity concentrations
Resilience/Vulnerability	Lake trophic status (slow response)
Sustainability measures	Aquatic ecological health
	Water quality ranges

TABLE 2. **Adaptive cycle for phytoplankton in Te Waihora/Lake Ellesmere.**

ADAPTIVE CYCLE COMPONENT	BIOPHYSICAL PROCESSES
Exploitation Effects of nutrient inputs from human activity and natural processes. Role in the food chain	Development of algal biomass in response to nutrients and other growth requirements. Food source for zooplankton
Accumulation Lake as habitat	Retention and growth of algae in the water column
Release/disturbance	Dilution from inflows and discharge from lake via artificial opening to the sea
Reorganisation	Return to lake conditions
Channel closure	reduced algal biomass. Rate of new growth and quantity of biomass dependent on size and distribution of residual populations, lake volume, temperature, wind climate, salinity gradients, light, nutrients etc
Resilience/Vulnerability	Lake trophic status
Sustainability measures	Water clarity

TABLE 3. **Adaptive cycle for Short and Long legged wading birds.**

ADAPTIVE CYCLE COMPONENT	BIOPHYSICAL PROCESSES
Exploitation	Birds use shallow water for feeding, especially in the main mudflat areas
Accumulation Lake as habitat	Rise in lake levels slowly ‘drowns’ wading bird habitat
Release/disturbance	Lake opened to the sea exposes mud flats
Reorganisation	Return to lake conditions
Channel closure	mudflats exposed for feeding, occasional windlash re-wets over summer period
Resilience/Vulnerability	Numbers of key indicator species
Sustainability measures	Achievement of diversity index

mental framework within which adaptive cycles and their connections can be understood. With respect to lake processes, relevant time scales range from thousands of years (e.g., lake formation and infilling) to weeks or days (e.g., lake openings and storm events). Between these are timeframes of hundreds of years (climate change and sea level rise), tens of years (rainfall variability), and seasons (e.g., patterns of bird migration and the balance between rainfall and evaporation). Sustainable management requires explicit recognition of the importance of scale and the potential for intervention at one level to manifest across multiple scales. Thus lake level control may involve day-to-day decision making, but have impacts on cycles with a seasonal (e.g., fish passage) or even geomorphological time scale (sedimentation). Similar considerations apply to spatial scales, which range from whole-of-catchment perspectives (land use and run-off, ground and surface water systems) to discrete areas associated with particular river mouths, salt marsh flats, or vegetation zones.

In summary, this view of the lake system, in which a series of interlinked adaptive cycles operate across a range of scales, presupposes a number of fundamental properties. These are:

- Resource limitation. There are finite limits to the resources (values) of the lake and its catchment, and these will become depleted or exhausted if adaptive cycles are not capable of fully resetting after disturbance.

- Resilience. Elements of the system are inherently resistant and adaptable but these qualities are constrained. Each species is adapted to a range of physical and chemical conditions, outside of which it will fail to thrive or survive.

- Connectedness. Processes taking place within the system are linked across space and time. Disturbances in one part of the system will inevitably impact on others, but not necessarily in the same location or at the same time. The act of lake opening at Taumutu will impact on salinity gradients 10 kilometers across the lake; it may also affect recruitment and migration of fish species a number of seasons hence.

This systems perspective has profound implications for management, albeit within a lake that appears to be in a continued state of flux, with multiple (and often unpredictable) cross-overs between cycles. Perhaps most importantly, it requires the integration of substantial amounts of knowledge across a range of disciplines. A characteristic of environmental decision making is the considerable uncertainty with which such decisions are often associated (Gough and Ward 1996). The advantage of a systems approach along the lines suggested here is that it offers an opportunity to identify knowledge gaps and account for their attendant risks in a structured and coordinated way. Provided potential interventions are evaluated within a framework which recognises the interactions within and between processes with different spatial scales and timeframes, the potential is enhanced for decisions which produce positive outcomes, and reduced for unintended or adverse consequences.

Poor understanding of biophysical systems, or high levels of complexity, or both as in the case of Te Waihora/Lake Ellesmere, can act as a brake on environmental decision-making. Overwhelmed by a sense that a system is too difficult or complicated to deal with, managers may delay or avoid improving their knowledge of the resource or developing policy. The framework proposed here offers a means by which decision makers can proceed with improved confidence. At the same time, the systematic approach encourages scientists and managers to recognise and account for 'controlling factors'. These are the principal chemical and physical components of the system that control the abundance and diversity of organisms within it. Identification of these elements simplifies the process by which adaptive cycles, their interdependencies, and the ways in which they may be impacted, can be described and understood. For example, Davis *et al.* (1996) identified seven environmental factors that were fundamental to the Te Waihora/Lake Ellesmere food web: nutrients, turbidity, dissolved oxygen, salinity, lake level, water surface area, and lake bed sediment movement. Subsequent analysis of the impacts of various management options on the lake ecosystem was based on the effects of those options on the seven factors. Similarly, our understanding of those factors helped inform the assessment of the drivers of change to lake values described later in this paper (Table 7).

TABLE 4. **Past and present value ratings for Te Waihora/Lake Ellesmere.**

Resource	Past	Present
The Ngai Tahu Values	National	Regional
Indigenous vegetation	International	National
Indigenous fisheries	International	Regional
Wildlife	International	International
Recreational fishing	International	Local
Recreation	International	Regional and local (activity dependent)
Farming	▪ Local (lake edge) ▪ Regional (lake environs)[3]	▪ Individual (lake edge) ▪ Regional (lake environs)

11.3 The overall state of the lake

The 'values' and their significance

The state of the lake's 'values'[4] can be considered at individual, local, regional, national and international levels, with respect to the past, the present and potential future(s). So, without defining details of each value here (i.e., they are defined in the separate background papers already referred to) it is possible (from each of these papers and from discussions held with scientists at the two research workshops) to rate the level at which the values are significant (Table 4) - clearly the lake has values that range from internationally significant (wildlife) to individual (lake edge farming).

Clearly, for most of these resources there have been major declines in their significance/

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[3] Note that for the purpose of this research 'lake environs' refers to the land between the lake edge and the sealed roads to the north, west and south, and to the shingle road along Kaitorete Spit. However, the importance of the connections between the lake, the wider catchment (i.e., Bank Peninsula, and the plains and foothills to the west, and the marine environment should not be underestimated. This latter connection in terms of long term predicted climate change influences on the lake could be extremely important, especially in terms of sea level rise and the ability to maintain the current lake opening regime.

[4] An argument can be made that 'values' is inappropriate terminology. The argument is based around the relatively new concept of ecosystem functions and associated ecosystem services. Values can be attached, and frequently are, to such services. While we acknowledge this approach has much merit we are of the view that 'values' is a term easily understood by scientists, managers and the community and have thus retained its use.

TABLE 5. **Summary of resource values, indicators and trends in Te Waihora/Lake Ellesmere and its catchment.**

Values	Indicators of Change	Trends	Value of trend
Catchment Hydrology			
Selwyn R.flows:			
Upper catchment	Flow	No change	
Coes Ford	Flow	Decline	-ve
Most other spring-fed streams	Low flow	Decline 1997-2007	-ve
Groundwater levels	Levels in monitoring wells	Decline, especially since 2000	-ve
Water quality of tributaries			
Nutrients	Change in concentration	Decrease 1993-2007 (ex Kaituna: no change)	+ve
Flow	Change in base flow/floods	Decrease	-ve
Sediments	Flood events	Decrease	+ve?
Water quality of lake			
Nutrients	Change in conc. nitrogen	Decrease 1993-2007	+ve
	Change in conc. soluble phosphorus	Increase	-ve
Chlorophyll a biomass	Change in concentration	No change	~
Suspended solids	Change in concentration	No change	~
Clarity	Change in light transmission	Decrease	-ve?
Salinity	Change in concentration	Decrease	?
Vegetation			
Lakeshore vegetation	**Area of**		
Community extent	Saltmarsh/brackish	Decrease 1984-2007	-ve
	Freshwater wetland habitat	Increase	+ve/-ve
	Marsh ribbonwood	Increase	+ve
	Three-square sedgeland	Increase	+ve
	Exotic grassland	Decrease	+ve
	Native freshwater wetland	Decrease	-ve
	Grey/crack willow	Increase	-ve
	Areas of high botanical value: Western shore	Decrease	-ve
	Remainder	No change	~
Threatened species			
Nationally threatened	chronically threatened plants:	Decline 1984-2007	-ve
	At risk plants:	Range restricted	-ve
Locally rare and uncommon species			
Locally rare	Locally threatened	Decline	-ve
Absent	Possibly lost	Serious decline	-ve
New introductions	Revegetation	Increase	+ve
Freshwater wetland species	Natural spread	Increase	+ve
Unusual plants of boggy sites	Rare	No change	~
Weed species			
Desirable habitats for weeds	Range of habitats	Increase	-ve
Brown trout recreational fishery			
No. individuals	No. spawning	Decline 1941-2007	-ve
By-catch	No. caught	? Increase	-ve
Tributary water quality	Clean gravels, clear water Number fish migrating	Decrease	-ve
Selwyn R. low flows	Migration	Decrease	-ve
Aquatic macrophyte beds	Area of beds	Decline	-ve
Commercial fisheries			
Eel (tuna) Shortfin			
No. individuals	Catch records	Decrease 1973-83	~

TABLE 5. **Continued,**

Values	Indicators of Change	Trends	Value of trend
After quota introduced		No change 1983-2006 Female to male dominated fishery	-ve
Feeding fish	Growth rate	Increase 1974-2007	+ve
Migrant fish - male	Growth rate	No change	~
Migrant fish - female	Growth rate	Increase	+ve
	Annual recruitment	?	
Longfin eel			
No. individuals	Catch records	Decrease 1974-2007	-ve
	Growth rate	No change	~
Flounder (patiki)			
No. of individuals	Catch records	Variable 1983-2006	~
	Recruitment of juveniles	Variable	~
Yelloweye mullet			
No. of individuals	Catch records	Variable	~
	Recruitment of juveniles	Variable	~
	Market demands	Variable	~
Wildlife			
Species diversity	Species no. & range of guilds	Stable	+ve
Conservation & taonga species	No. of breeding pairs	Declining	-ve
Sustainable harvest species	Annual nos.	Stable	+ve
Habitat availability	Range of habitats	Declining	-ve
Recreation			
Diversity of opportunities	Range of recreational opportunities	Stable (but activity mix changed)	+ve
Quality recreational experiences	% reporting positive experience	Cycling increasing	+ve
		Other activities Stable or Decreasing	-ve
The Ngāi Tahu Values			
Mahinga kai	Availability of mahinga kai	Declining	-ve
High quality habitat availability	% of key aquatic, wetland and terrestrial habitats	Declining	-ve
Human perception of lake	Increase in Ngāi Tahu whanui accessing lake	Declining	-ve

value between the past and the present.

Changes to values

As noted in the individual reports on the biophysical resources of the lake, changes in the state of the lake have occurred over the past 10 to 15 years (i.e., since 1996). This is not surprising in a complex ecosystem (see systems diagram, Figure 1) subject to variations in inputs and climate over recent years. While some of the values have shown little change, most have shown distinct increases or decreases. These trends are summarised in Table 5.

Hydrological trends (Thorpe 2007) in the Lake Ellesmere catchment indicate that while the Selwyn River flows in the upper catchment at Whitecliffs show no change, at Coes Ford the flows are declining. Changes to water table elevation and varying spring flows are due mainly to variability in rainfall exacerbated by increased use of groundwater and surface water for irrigation. This has led to decline in monitored flows overall, and especially during the summer irrigation season. The monitored decline in flows correlates with a similar overall decline in groundwater levels, only some of which may be ascribed to climate.

Water quality trends are based on monthly data collected from 1993 (Hayward 2009). The tributaries contribute the major source of nutrients to the lake, although nutrient loads have decreased in recent years due to lower base flows and less frequent floods. The body of the lake also has lower concentrations of total nitrogen and phosphorus. While suspended solids have not changed, water clarity has decreased. Chlorophyll biomass has not changed suggesting that the nutrients are not limiting to phytoplankton growth. Climate and lake level are influencing phytoplankton production. Salinity may have decreased significantly in the lake probably related to fewer lake openings and lower lake levels.

For lakeshore vegetation including locally rare and uncommon plants, trends have been identified by comparison of the survey of Clark and Partridge (1984) with a survey in 2007 (Grove and Pompei 2009). The overall extent of freshwater wetland habitats has increased and brackish wetland vegetation decreased. However, several lakeshore native brackish vegetation communities such as marsh ribbonwood shrubland and three square sedgeland have increased, while the area of native freshwater wetland has decreased over the period. Exotic brackish grassland communities have decreased while exotic grey and crack willow have increased in freshwater wetland habitats. Several areas of high botanical value listed by Clark and Partridge (1984) have persisted but smaller important wetlands on the western shore have decreased in area.

Threatened plant species (Hitchmough *et al.* 2005) have also been compared using the survey of Clark and Partridge (1984) by Grove and Pompei (2009). Nationally and at the lake, some threatened plants are in gradual decline, e.g., pingao, swamp nettle, sea holly, a willowherb and mud pond weed. Purple musk is nationally at risk and prostrate broom has a restricted range and is also at risk. Four indigenous species may have been lost from the lake environs in the past 27 years while other plants such as marsh gentian have been found. Small unusual plants of boggy sites such as bladderwort, sundew and ladies tresses orchid are still rarely found.

The brown trout recreational fishery, purportedly the best in the world, has dramatically declined since the 1940s when numbers peaked at 65,000 trout spawning in the Selwyn River. In 2007 numbers are estimated at 250 (Millichamp 2009). Possible causes of decline include by-catch of commercial fishing; decrease in quality of spawning habitat in tributary streams where clean gravels and clear water have been reduced; loss of access to Selwyn River headwaters for spawning due to low flows; loss of rearing habitat and protection from predators in the lake with the removal of the aquatic macrophyte beds and clear water during the Wahine storm in 1968.

Commercial eel (tuna) and flounder (patiki) fisheries have catch records going back to 1973 and 1945 respectively (Jellyman and Smith 2009). There was a decreasing catch of eels from 1973 to 1983 before quota was introduced in December 1978 and sustainable catch from 1983 to 2006. The fishery has changed from female to male dominated. Growth rates of feeding shortfin eels have increased from 1974 to 2007 while feeding longfin eels show little change over this period. Migrant male shortfin eels have also shown little change in growth rate while migrant female shortfins show accelerated growth with increasing size associated with their change from invertebrate to fish diets. Migrant males are too small to eat fish. Flounder and yelloweye mullet catch records have been highly erratic from 1983 to 2006 due to variable recruitment and, for mullet, market demands.

For wildlife, bird numbers/species diversity (collected primarily in the 1980s) have been updated from the 1996 report with data from 2005 and 2006 (Hughey and O'Donnell 2009). The lake is of international significance for its wildlife values, based around its very high levels of species diversity, presence of very large numbers of birds, its importance as a migration stopover point, and the presence of a large number of threatened species. It is proposed that species diversity should be maximised with target levels from the seven guilds recorded annually. Populations of species at risk such as Australasian bittern, banded dotterel, Caspian tern and grey teal require specific conservation management. Harvestable species such as black swan, Canada goose and mallard duck need sustainable management if they are not to cause damage to the lake and surrounding land. Different ranges of habitat conditions are required and have been defined for the different groupings of wildlife species that rely on the lake, particularly in terms of lake level and riparian management.

The lake is a regional recreational resource for wildlife-related activities (Booth 2009), but also hosts a wide range of other water- and land-based activities (from walking and biking to waterskiing and kayaking). Key indicators include the range of opportunities, numbers participating, quality of the recreation experience and the amount of off-site information identifying lake-related recreation opportunities (to measure public recognition of recreation values). Some

Photo ***Lake Ellesmere and it's environs has values that range from being internationally significant (wildlife) to individually important (lake edge farming), but many of these are in decline. Future successful management of these values will require a system-based approach to willow for the complex relationships between environmental factors and the uses and values placed on the lake.*** *Photography* ***Colin Hill.***

activities are increasing in importance, e.g., the Rail Trail for biking, while others are declining (recreational fishing for example). Potential exists to extend the range of activities and the opportunities associated with existing resources, e.g., birdwatching (which has international interest). Management requirements include water quality and quantity improvements, information provision, improved and appropriate access provision and managing the lake opening regime for recreational purposes.

The lake and its environs are important economically (Butcher 2009). There is commercial fishing ($650,000 / yr), farming ($34 m / yr) and non-commercial values related to mahinga kai, recreation (including fishing $150,000 / yr) and ecosystem services. Of the farming production, $4.5 m / year occurs below the 1.7 m contour and is affected by high lake levels, and flooding due to wind lash. Higher land is occasionally flooded and is also affected by high ground water levels reducing workability, and by impacts on farm management if low-lying land is not available for grazing. The annual cost of lake openings is $164,000 / year, 70 % of which is met by affected land-owners and 30% of which is met by the general public. Possible changes to lake management regimes could be associated with a decline in farm production, increased farm costs, and increased mahinga kai and recreational (including fishing) values. Equally, changing economic signals associated with currently high commodity prices for milk products have driven pressures for more dairy land development with often negative consequences of habitat and species.

Te Waihora is of immense importance to Ngāi Tahu (Pauling and Arnold 2009)—as a mahāinga kai site and for other reasons. Major changes, mostly negative, have occurred over time, e.g., with respect to loss of aquatic habitat for mahinga kai, loss of matauranga maori related to mahinga kai, reduced use of the lake for mahinga kai, and degradation of the mauri and mana of the lake, its people and mahinga kai. Management requirements can be identified and revolve primarily around water quality and quantity improvements.

The indicators of change and trends summarised in Table 4 are affected by changes in the system (see the systems diagram: Figure 1) caused primarily by human-induced changes to biophysical factors. These are the drivers of change.

This evaluation of state, at the 'value', and individual and multiple indicator levels, delivers a complex set of signals about the 'health'[5] of the lake that matches the complexity of the lake itself. It should not surprise that there are ranges of positives and negatives. This range can be summarised within each of the value sets (Table 6). The 'health' or 'state of the lake' ratings summarise Table 5 and are based on a five point scale ranging from 'very good' to 'very poor'. Such scoring systems are used in other natural resource management contexts to provide a measure of the relative well-being of biological communities or ecosystems (e.g., aquatic ecosystem health assessments) or suitability for use (e.g., recreational water quality gradings). In assigning these relative scores for lake values we have used as our point of reference the best possible state that could be envisaged, bearing in mind the need to account for the fact there is no one set of environmental conditions that is optimal for all values.

This overall evaluation leads to the conclusion that no one rating defines the 'state' or 'health' of the lake. Nevertheless it is possible to conclude, and despite water quality and quantity issues and other management concerns, that the lake is a remarkably resilient system. Many 'values' have components in the 'fair' to 'very good' range, with others

TABLE 7. **Key drivers of changes to values of Te Waihora/Lake Ellesmere.**

Drivers	Values		
	Water quality	Lakeshore vegetation	Threatened plant species
Lake level management	X	X	
Change in water quality	X	X	
Change in salinity	X	X	X
Change in phytoplankton & invertebrate food	X		
Lake bed sediment movement/suspension	X	X	
Change to inflows & linked habitats	X		
Loss of macrophyte beds in the lake	X		
Habitat loss (where otherwise not included)			X
Poor riparian management		X	X
Weeds		X	X
Commercial fishing practices			
Change in recreational fish stocks			
Rail trail			
Access and information		X	X
Poor aesthetics			

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[5] We accept that health, even ecologically, has a variety of contexts, e.g., Human utility generated lake through ecosystem services; Overall ecosystem biodiversity; Overall system resilience; Overall primary production in the lake; Overall ecological functioning; or many other objective functions. In this context we take an holistic view of health as reflecting the 'entirety' of the ecosystem and its state.

that are ‘very bad’ but mostly surviving. Only one value, the brown trout fishery, is considered to be in a ‘very bad’ state. Given this range of states what then are the key drivers of change?

11.4 Drivers of change to indicators/values

The indicators and trends identified in Tables 5 and 6, and the principal chemical and physical determinants of biological diversity and abundance, can clearly be linked to drivers of change (Table 7)—this summary is based on the background research of the scientists referred to in this Section. These drivers of change can, if necessary, be considered at a more detailed level as per Davis *et al.* (1996) who developed a framework for thinking about communities and key changes that would have the greatest effects on these communities (see Appendix 1). Mostly the 2007 situation is similar to that from 1996 but with two notable exceptions: in 1996 grey willow was not considered a weed of importance yet it is now a major ecological problem for freshwater wetlands; and in 1996 farming was the dominant land use adjacent to the lake whereas now it is conservation lands.

Overall the summary of drivers gives a further and probably not surprising indication of the importance of lake level management and water quality to most of the key value sets. It is not surprising, therefore, that many of the management actions will be constructed around dealing with these drivers of change.

11.5 Desired futures for Te Waihora Lake Ellesmere and proposed management actions

Framework considerations

The work detailed in Taylor (1996) (and here) indicates the complexity of different systems and the incompatibility of outcomes associated with Te Waihora/Lake Ellesmere. The 1996 report also highlighted the interdependencies between different components of the system. It is therefore difficult, if not impossible to establish a management framework that will deliver optimum outcomes for each component (or value). Tradeoffs are inevitable.

In circumstances like this adopting a

TABLE 6. **Summary of ‘value’ states for Te Waihora/Lake Ellesmere ‘values’.**

‘Value’	Range of states
Catchment Surface Hydrology	Upper: ‘very good’
	Lower: ‘very bad’
Catchment Groundwater Hydrology	‘bad’ to ‘very bad’
Water quality of tributaries	‘good’ to ‘very bad’
Water quality of lake	‘fair’ to ‘bad’
Vegetation	Vegetation: ‘very good’ to ‘poor’
	Rare plants: ‘very good’ to ‘bad’
	Weeds: ‘very bad’
Brown trout recreational fishery	‘very bad’
Commercial fisheries	‘good’ to ‘bad’

Values						
Recreational trout fishery	Commercial fisheries	Wildlife	The Ngāi Tahu Values	Recreation	Farming	Totals
	X	X	X	X	X	7
X	X		X	X		6
X	X				X	6
X	X	X				4
X						3
X			X		X	4
X	X	X	X			5
X		X	X			4
X	X		X			5
		X			X	4
X			X			2
				X		1
				X	X	2
X		X	X	X		6
				X		1

panarchic framework has merit. It enables description of the key adaptive cycles related to the system under consideration and identification of the possible points of intervention for management. It also focuses on the resilience (or vulnerability) of each biophysical cycle. For a complex interactive system like Te Waihora/Lake Ellesmere, keeping each adaptive cycle within its sustainability range is critical to the effectiveness of a framework for management.

In establishing a management framework the key elements are:

- Identification of the environmental, economic, social and Ngāi Tahu values to be protected
- The definition of the adaptive cycle related to each of these values
- The points of intervention in that adaptive cycle for possible management actions and
- The ranges of key sustainability variables which assure the resilience of the adaptive cycle for that value.

And, of course, in addition there are the statutory and non-statutory policy and planning frameworks within which the above have to operate. We have decided to largely ignore the detail of the policy and planning documentation of the statutory and non-statutory agencies, except in-so-far-as key visions and goals can be identified. Rather, we are operating under the assumption that the lake is of such high importance that specific plans and procedures will work and be mutually adjusted where necessary to achieve these desired visions and goals.

Based on the above a management 'frame' is needed to act as the vehicle for goal setting and change management.

Given the complexity of the lake ecosystem there are arguments for:

- Systems based approaches, which recognise the need for resilience
- Setting of broad goals and specific objectives and targets
- Establishing an encapsulating goal-oriented status, e.g., some sort of park, perhaps building on the IUCN Wetland of International Importance idea
- Identification of value sets and broad ranges of tolerance within objectives and targets to allow for the mix of some potentially conflicting values, e.g., grazing vs short legged wading bird habitat.

None of these is exclusive. More than one component is required to develop an effective framework for lake management. We suggest a combined approach in which adaptive cycles provide a basis for identifying the impacts of interventions in a fully integrated way, and an objective-based management approach that allows for pragmatic goal setting, identified management actions and response planning.

Implicit in this approach is the need to recognise and account for tolerance ranges and conflicts between values. This overall approach recognises a degree of complementarity between existing management actions and the need to take action. Such action may be necessary where 'values' and trends in indicators thereof, e.g., loss of swamp habitat resulting from the rapid increase in grey/crack willow, suggest if action is not taken now there might be irreversible consequences.

Based on the above it became clear to us that some short-term management actions need to be proposed and agreed upon, built around three criteria:

- the action deals with a driver of change that if not 'treated' now will irreversibly impact on values, e.g., weed invasion impacting on wildlife and indigenous vegetation; or, protection of all remnant indigenous vegetation and riparian values
- the action does not compromise other significant value sets, e.g., control of willows in Harts Creek, while possibly affecting a few people who like willows, has no significant adverse impact and
- the action is cost effective[6] in achieving the desired outcome(s).

The above approach then allows us to think more strategically about what else is necessary, in the longer term and in the broader geographical scale, to maintain and enhance the values of the lake.

Proposed goals for the lake

Multiple community and statutory planning documents have been prepared for Te Waihora/Lake Ellesmere. To promote dialogue, within the broader regional context (recognising the role of the wider community in contributing to the resourcing of management interventions), we propose a connection between the Regional Policy Statement call for improved water quality, the overarching sustainability and restoration goals of the WET community strategy and the Ngāi Tahu-Department of Conservation Joint Management Plan vision. To this end we propose the following vision, amended (where underlined) to deal with a broader geographic scale:

> *"Ngāi Tahu cultural identity and community respect is restored through the rejuvenation of the mauri and life-supporting capacity of Te Waihora.*
> *The Lake Area (including Joint Management Plan area) is managed in an integrated manner for "mahinga kai, conservation and other purposes", in a way that enhances the enjoyment of the wetland for all New Zealanders.*
> *Management of the Lake Area (including Joint Management Plan area) provides an example that can be promoted for the management of the entire lake margin and the adjoining inflowing tributaries and their wetlands."*

The vision is comprised of the following components:

- Enhancing mana
- Enhancing mauri and therefore the natural and spiritual values of the area
- Supporting indigenous biodiversity
- Enabling the gathering and use of mahinga kai

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[6] In this context cost effective means the financially least cost option for delivering the selected (mostly) bio-physical environmental outcome.

- Providing for compatible recreational use and enjoyment
- Providing for compatible commercial opportunities (including tourism opportunities)
- Recognising the national and international significance of Te Waihora
- Developing awareness of other management tools and agency processes while supporting holistic management."

Consistent with the above we suggest three scenarios to provide a contrasting framework within which lake futures can be discussed.

Scenarios

The following three relatively easily identifiable scenarios for the lake (which are consistent with the visions in the JMP and the WET Community Strategy), will require management actions at various levels and scales, spatially and temporally:

- An improved status quo incorporating ongoing (but recent) management initiatives and their maintenance
- A realistic and resilient environmentally enhanced future which is built around a set of achievable, short, medium and longer term goals and is based on a compromise between the enhancement of 'natural' values and considerations of technical and economic feasibility[7]
- An idealised future based on strict conservation management principles.

These scenarios have the resource attributes identified in Table 8.

Management actions and the future scenarios

Each of the three scenarios contains associated management actions as follows (with the main benefiting resources shown in brackets (i.e., [ ]). It should be noted that for each set of actions there is predicted to be ongoing flow-on benefits, over time, and sometimes over broader geographic scales, but there are large areas of uncertainty. Consistent with the variable scales of adaptive cycles, therefore, we have specifically attempted to integrate both the spatial and temporal aspects in the following contributions. Note, of course, that 'longer term' in these cases is very short compared to the time frames over which some likely drivers of change to the lake operate, e.g., climate change and sea level rise, and sedimentation. The three tables (9-11) respectively represent scenarios 1-3.

Depending on which scenario, or combination of activities from the scenarios, is adopted, and the time for achieving desired outcomes, then likely future benefits can be summarised as changes to the status of values (Table 12).

Perhaps the biggest limitation to this evaluation is the lack of any reference to the comparative costs and benefits of some management actions. Management costs will vary greatly-some will be very inexpensive,

TABLE 8. **Future scenarios for Te Waihora/Lake Ellesmere and their value attributes.**

Resource	Improved status quo and maintenance	Realistic and resilient environmental future	Ideal conservation based
The Ngāi Tahu Values	Moderate Ngāi Tahu values	High Ngāi Tahu values including improved mahinga kai access[8]	Outstanding Ngāi Tahu values including improved mahinga kai access, and restoration activities
Indigenous vegetation	High value native vegetation protected and some revegetation	High value native vegetation, including restored areas, all diversity retained	High value native vegetation, including restored areas, all diversity retained, major revegetation efforts
Indigenous fisheries	Sustainable commercial eel fishery	A sustainable eel and flounder fishery	Maintain and increase species diversity, increase eel numbers, increased customary harvest
Wildlife	High wildlife values including maintenance of species diversity	High wildlife values including maintenance of species diversity, including restoration of swamplands	High wildlife values including maintenance of species diversity, including restoration of swamplands, and reintroduction of brown teal and SI fernbird
Recreational fishing	Poor value trout fishery	Regionally significant trout fishery	Nationally important trout fishery
Recreation	Moderate recreation in terms of both level and quality	High recreation use, in terms of both level and quality, and awareness of opportunities, not conflicting with conservation[9] and Ngāi Tahu cultural values	Very high levels and quality of recreation use, not conflicting with conservation and Ngāi Tahu cultural values
Farming	Individual value to farmers retained with some minor loss due to changes in lake level management	Reduced farming around edge as land purchased and more conservation grazing	Conservation grazing only; Fencing off stock from all inflowing streams, or supplementation of flows
Water (quality and quantity)	Maintain existing flows and groundwater levels	Improved flows, groundwater levels and water quality	Improved flows, groundwater levels and water quality

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[7] Note, for all scenarios integrated monitoring and adaptive learning programmes are necessary.

[8] Some or all of the following aspects will need to be dealt with depending on context: legal and physical passage, legal 'take' controls, species population availability.

[9] Defined as preservation and protection of values, consistent with the Conservation Act 1987.

TABLE 9. **Scenario 1: An improved status quo incorporating ongoing (but relatively recent) management initiatives and their maintenance.**

Spatial scales	Temporal scales		
	Short term: <5 years	Medium term: 5-10 years	Longer term: >10 years
Lake level	▪ Existing practice	▪ Existing practice	▪ Existing practice
Lake bed management	▪ Investigate macrophyte re-establishment, undertake weed control [fish, wildlife, vegetation]	▪ Continue all short-term actions	▪ Continue all short and medium term actions
Riparian management	▪ Active programme to maintain native vegetation and begin restoring key areas [vegetation]	▪ Continue all short-term actions ▪ Undertake willow control in key areas [vegetation, wildlife]	▪ Continue all short and medium term actions
Catchment management	▪ Active programme to maintain current and where possible increase stream flows and groundwater levels (restorative streams consents review programme)	▪ Continue all short-term actions ▪ Restore flows and groundwater levels as consents renewed and community irrigation schemes developed	▪ Maintain restored flows

TABLE 10. **Scenario 2: A realistic and resilient environmentally enhanced future built around a set of achievable, short, medium and longer term goals based on a compromise approach.**

Spatial scales	Temporal scales		
	Short term:<5 years	Medium term:5-10 years	Longer term:>10 years
Lake level	▪ Research (and if beneficial) implement spring opening, S-O, where forecasted conditions appear suitable [indigenous fish, trout]	▪ Maintain opening and closing regimes	▪ Maintain opening and closing regimes
	▪ Establish autumn opening [trout]	▪ Higher average lake level [native vegetation, swampbirds, fish habitat]	▪ Investigate permanent controlled outlet and if feasible implement [fisheries, wildlife, vegetation]
	▪ Implement closing regime [wildlife, native vegetation]		
	▪ Research (and if beneficial) implement changed commercial fishing practices [trout]		
Lake bed management		▪ Trial macrophyte re-establishment, after lake level management changes [fish, wildlife, vegetation]	▪ Continue all short and medium term actions where beneficial
Riparian management	▪ Via policy initiatives, etc., ensure no further loss of native vegetation [vegetation] allowed	▪ Maintain benefits from all short-term actions and	▪ Continue all short and medium term actions where beneficial
	▪ Begin significant revegetation programmes [vegetation]	▪ Undertake willow control in key areas [vegetation, wildlife]	▪ Re-introduce brown teal for conservation and Ngāi Tahu cultural harvest purposes [Wildlife, The Ngāi Tahu Values]
	▪ Negotiate changed farming practices to achieve conservation outcomes	▪ Protect key riparian habitats [fish, wildlife, vegetation]	
	▪ Acquire and manage remaining lake edge farmlands	▪ Investigate the re-introduction of brown teal for conservation and Ngāi Tahu cultural harvest purposes	
		▪ Implement changed farming practices to achieve conservation outcomes	
Catchment management	▪ Active programme to maintain current and where possible increase stream flows and groundwater levels (restorative streams consents review programme)	▪ Restore flows and groundwater levels as further consents renewed and/or community irrigation schemes developed	▪ Maintain restored flows and groundwater levels
	▪ Develop and implement a nutrient management programme	▪ mplement further nutrient reduction measures	▪ Maintain and improve nutrient management programme

TABLE 11. **Scenario 3: An ideal future based on strict conservation management principles.**

Spatial scales	Temporal scales		
	Short term: <5 years	**Medium term: 5-10 years**	**Longer term: >10 years**
Lake level	▪ Research and (if beneficial) implement spring opening, S-O, where forecasted conditions appear suitable [indigenous fish, trout] ▪ Establish autumn opening [trout] ▪ Implement closing regime [wildlife, native vegetation] ▪ Research (and if beneficial implement) changed commercial fishing practices [trout]	▪ Maintain opening and closing regimes (where proven beneficial for conservation purposes) ▪ Act to result in higher average lake level [native vegetation ▪ Investigate permanent outlet with management focused on environmental outcomes [fisheries	▪ Maintain opening and closing regimes, and if appropriate from previous: ▪ Build and operate permanent outlet operated under a conservation management regime [fisheries, wildlife, vegetation]
Lake bed management	▪ Investigate and trial macrophyte re-establishment, undertake weed control [fish, wildlife, vegetation], after lake opening and closing regimes implemented	▪ Major macrophyte re-establishment programme [fish, wildlife, vegetation]	▪ Continue all short and medium term actions
Riparian management	▪ Via policy initiatives, etc., ensure no further loss of native vegetation [vegetation] allowed ▪ Begin significant revegetation programmes [vegetation] ▪ Initiate major willow control ▪ Begin programme to protect all riparian zones in tributary inflows ▪ Negotiate changed farming practices to achieve conservation outcomes ▪ Purchase/acquire lake edge properties and manage for conservation	▪ Willow control completed [vegetation, wildlife] ▪ All riparian habitats protected [fish, wildlife, vegetation] ▪ Re-introduce brown teal for conservation and Ngāi Tahu cultural harvest purposes ▪ Implement changed farming practices to achieve conservation outcomes ▪ Acquire remaining lake edge properties and manage for conservation	▪ Continue all short and medium term actions ▪ Major enhancement programmes underway.
Catchment management	▪ Very active programme to increase stream flows and groundwater levels (restorative streams consents review programme) ▪ Ensure community irrigation development contributes positively to water quantity and quality changes	▪ Continue to restore flows and groundwater levels as consents renewed and community irrigation schemes developed ▪ All new catchment developments have nutrient and sediment budgets with a lake focus	▪ Maintain all short and medium term actions

TABLE 12. **Evaluation of likely changes to value ratings if different management scenarios implemented.**

Resource	Past	Present (= Future 1: Modified status quo)	Future 2: realistic optimised tradeoffs	Future 3: ideal conservation based
The Ngāi Tahu Values	National	Regional	National	International
Indigenous vegetation	International	National	National	International
Indigenous fisheries	International	Regional	National	International
Wildlife	International	International	International	International
Recreational fishing	International	Local	National	International
Recreation	International	Regional	National	International
Farming	Local (lake edge)	Individual (lake edge)	Individual-conservation oriented	Individual – conservation focused
	Regional (lake environs)	Regional (lake environs)	Regional (lake environs)	Regional (lake environs)

some will not. Examples of major actions with major costs follow. Butcher (2007) has found (with limited access to 'hard data') that the costs of fencing all 'significant' waterways within the study area would be around $0.8 m, potentially foregone agricultural production under a conservation management regime would be about $1.8 m, with net income losses being $0.8 m / yr, and restoring key river and stream flows by reducing irrigation use would cost around $8-18 m (NPV) based on a requirement for around 1-1.5 m3/s of increased flow in dry years. Hearnshaw (2007) has considered the ecosystem management potential of a range of possible management actions and has found that a permanent lake outlet (controlled flow outlet) would have a 'present value' cost over a 25 year period of $36,140,000. The broader community will need to undertake a detailed evaluation of all actions in light of likely and comparative benefits and costs.

11.6 Conclusions and recommendations

Judge Smith (Lynton Dairy Ltd v. The Canterbury Regional Council, Environment Court C108/2005: at paragraph 101) stated:

"Te Waihora (Lake Ellesmere) was a significant shock to the Court. The lake is eutrophic, green in colour and seems to be devoid of any riparian management. For example, stock seem to have free access to the water, the margins appear to be subject to chemical spraying regimes and lake levels manipulated for farming rather than the natural values. The lake water is in a serious ecological condition and is in urgent need of attention. Riparian management is required as an absolute minimum."

The media in turn refined this statement to "... the heavily degraded lake was declared technically dead this year after Environment Court Judge Jeff Smith found it was in a serious ecological condition and virtually unable to sustain animal life"[10]. Jeanette Fitzsimons, the Green Party Co-leader, used the phrase "Lake Ellesmere is biologically dead" in the Address in Reply Debate in Parliament, 15th November 2005[11]. These statements spurred a number of researchers and managers to debate not whether the lake was dead, but just how healthy it really is. The lake, its environs, and the multiple interacting biophysical and human-induced variables are enormously complex. Nevertheless we have set out, via individual pieces of research (referred to in Sections 1 and 3), to consider the state (health) of the lake, compared to 1996 (when the Taylor (1996) resource report was released), indicators and key drivers of change, and possible scenarios and associated management actions for the lake.

Overall then we have found the lake is far from 'dead'[12]. Indeed only one value, albeit a very significant one, can be defined as being close to 'terminally ill'-the once 'world's best' brown trout fishery. Whether this value is recoverable is a matter of speculation, but nevertheless there do appear to be management and research actions that could be taken to promote the recovery of this fishery. All other resource/value sets have mixed report cards with many indicators showing that conditions are either static (which in many cases is a positive sign) or in decline (being 'off colour' to even 'very sick' in some cases). In our view the lake can at best be described, in human health terms, not as 'dead' but as 'a bit sick'-parts of it are in reasonable to good health but many others need attention.

In terms of improving the health of the lake we have developed three possible scenarios and sets of associated management actions. In our view the first scenario, an improved status quo, will be insufficient to move the lake to higher value states. This leaves us with scenarios' two and three-both have important attributes and in our view are likely to deliver 'significant' conservation and other outcomes, but at a cost (certainly in financial terms). It is up to the community to decide if this cost is worth bearing.

In progressing through this integration exercise and given the complexity of the lake system combined with the many other elements outlined above, there are a number of critical areas we need to research to try to achieve the outcomes identified:

- Environmental variable ranges (tolerance) need defining for key food chain and habitat components (see Sagar *et al.* 2004), e.g., salinity ranges for key saltmarsh vegetation maintenance;
- A better understanding of the biophysical implications of management interventions, disturbances and resetting mechanisms, e.g., the proposed closing of the lake at 0.6 m;
- An improved understanding of the timescales of responses, recognising interdependencies, e.g., willow clearance, followed by raupo re-establishment, followed by bittern use, but only also if predators are controlled and eels as a food resource increase;
- An agreed set of value states or goals that is more regional and national based to reflect likely sources of future management resourcing; and
- An investigation of the long term implications of climate change and sea level rises, especially the mid-term effects (perhaps 30-80 years) of relatively small sea level rises on the ability to both open and close the lake at currently desired levels.

Finally, if significant effort is to be made on the lake, consistent with scenarios' two or three, then a commitment to learning and adaptive management need to be made, from researchers, the community and statutory agencies. To this end we recommend an annual 'get-together' of the above to review progress, adjust plans, and coordinate activities, within an adaptively managed sys-

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[10] Source: http://www.waternz.co.nz/archives/2005_09_01_nzwaternews_archive.html Accessed 24 October 2007

[11] Source: http://www.greens.org.nz/searchdocs/speech9365.html accessed 24 October 2007

[12] The comparison with human health begs the question of 'how sick is sick?' Clearly the range can go from 'well' (which is equivalent to a thriving almost pristine environment) to 'terminally ill' (or an ecosystem or component parts suffering irreversible decline) with a range of intermediate points, perhaps from 'well' dropping to 'reasonably well', 'OK', 'off colour', 'a bit sick', 'very sick', 'seriously ill', to 'terminally ill'.

tems context. Such a gathering should occur no later than October of each year to fit budgetary cycles of the statutory agencies.

11.7 Acknowledgements

The following provided helpful comments: Philip Grove, Poma Palmer, Geoff Butcher, Hamish Rennie, Hugh Thorpe, and Kay Booth. We also thank all researchers for their inputs to the two research workshops. Finally, we appreciate the comments of Professor Ross Cullen and Ed Hearnshaw who reviewed the final draft of this paper, and then Trevor Partridge and Howard Williams for their post-symposium reviews.

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11.9 Appendices

Appendix A

Physical and chemical factors most affecting the biological communities of Lake Ellesmere (Source: adapted from Davis *et al.* 1996)

The following should be clear:

- For many communities there are ranges of drivers that have a variety of directional influences - benefit or cost, to the community;
- Given the multiplicity of communities it is clearly not possible to optimise for every situation - tradeoffs are necessary given all the competing values.

Shelley McMurtrie

Comments
A Decomposers
▪ Concentration related to lake productivity
Phytoplankton
B Blue-green algae
▪ Nodularia prefers higher salinities (10-15 ppt) than green algae in lake
C Green algae
▪ Most lake species are freshwater
D Benthic algae
▪ Occur in low numbers in lake
E Submerged macrophytes
F Zooplankton
▪ Directly dependent on availability of phytoplankton
G Benthic invertebrates
▪ Depend on lower trophic levels (benthic algae, periphyton, decomposers) for food ▪ Utilise macrophytes extensively as habitat
H Native fish
▪ Most have marine stage in life-cycle ▪ Visual feeders ▪ Cannot tolerate low oxygen levels
I Exotic fish
▪ Responses similar to native fish (H), except: ▪ Trout could be affected by increased nutrients ▪ Juvenile trout less tolerant of higher salinities than other fish in lake ▪ Lake openings

Environmental change that would have the greatest effect on community	Effects
Nutrient increase Reduction in turbidity, salinity and desiccation	May increase abundanc Indirect benefit through re-establishment of lake weeks because of stable sub-strata
Salinity increase DO reduction	Gain competitive advantage over other types of algae
Nutrient increase	Benefit
Reduction in turbidity	Benefit
Salinity reduction	Benefit
Increase in nutrients	Benefit all algae
Reduction in turbidity	Benefit green algae
Reduction in turbidity, salinity, lake level fluctuations, bed sediment movement	As for green algae, benefit from stable substrata.
Improved light penetration	Benefit
Reduction in turbidity and salinity Increase in lake surface area	Significantly improve prospects for re-establishment of beds
Large fluctuations in lake level	Desiccation of plants may occur
Nutrient increase Salinity reduction Reduction in turbidity	Similar to changes in abundance of green algae
Reduction in turbidity	Improve food supply
Increase in lake surface area	Extend available habitat
Increase in macrophytes	Extend available habitat
Increase in frequency of lake openings	Improve recruitment if timing of coincided with migration periods openings
Reduction in turbidity	Enhance ability to catch food
Weeds re-established	Habitat markedly improved
Increase in lake surface area	Extend available habitat
DO reduced	Detrimental effect
Increase in nutrient concentrations	Detrimental effect
Increase in salinity	Detrimental effect
Increase in frequency of lake openings	Allow fish to leave system Reduce extent of littoral feeding habitat

Shelley McMurtrie

Comments
J Plant-eating birds
▪ Submerged macrophytes primary food source
▪ Prefer relatively high, stable lake levels
K Insectivorous birds
▪ Feed on benthic invertebrates, zooplankton and terrestrial insects
L Carnivorous birds
▪ Feed on fish, other birds, mammals (not solely lake-dwelling species)
Lake-shore vegetation
Frequently submerged vegetation
▪ Occurs round lake margin on sandy or muddy soils where water table high and sediment mobile
▪ Zone typified by musk (*Mimulus repens*), a low-growing species dominating sandy lake flats below the 1.0 m contour
N Halophytic vegetation
▪ Salt-tolerant, occurs on sandy sites where water-table low
▪ Spends only short periods under water
▪ Zone typified by glasswort (*Sarcocornia quinqueflora*), short succulent plant growing in sandy, saline areas above level of lowest flats
O Freshwater vegetation
▪ Occurs on muddy/silty sites where water-table is high, water often ponded
▪ Zone typified by raupo (Typha orientailis) – grows up to 3 m tall on low salinity mud-flats
P Agricultural vegetation
▪ Occurs on fertile sites well above lake where water-table medium to low
▪ Presence of some halophytes (e.g., sea rush) within pasture represent remnants from former lake margin
▪ Area rarely inundated
▪ Zone typified by perennial ryegrass (*Lolium perenne*) which occurs on dry, freely draining land
Q Agricultural herbivores
▪ Basically comprise sheep and cattle
▪ Dependent on pasture
R Feral herbivores
▪ Basically comprise rabbits and hares
▪ Graze on pasture
▪ Suffer relatively less than agricultural herbivores because of greater mobility
S Feral carnivores
▪ Comprise ferrets, stoats, wild cats
▪ Birds, rabbits and hares principal food source
Humans – water
users T Fishers
▪ Includes both commercial and recreational
U Hunters
▪ Availability of eels, flounder, mullet for commercial fishing; trout, perch, whitebait, flounder, eels for recreational fishing
Humans – land users
V Farmers
▪ Farming is a minor land use adjacent to lake
▪ Agricultural production affected directly by area in pasture

Environmental change that would have the greatest effect on community	Effects
▪ Reduction in turbidity, salinity	▪ Improvement in lake's suitability for macrophyte re-establishment and growth ▪ Improve conditions for birds
▪ Significant reduction in lake size	▪ Significant adverse effect
▪ Changes that increase abundance of food sources	▪ Food supply improved
▪ Reduction in turbidity	▪ Improve visibility for hunting
▪ Lake surface area	▪ Benefit from increase
▪ Lake levels	▪ Benefit from greater range in lake levels
▪ Increase in salinity or turbidity	▪ Intolerant of these changes
▪ Reduction in salinity	▪ Lose competitive advantage from high salt tolerance
▪ Stable lake levels	▪ Lose competitive advantage from ability to withstand long periods of desiccation
▪ Increased nutrients	▪ Could be detrimental to some species
▪ Deposition of suspended sediment	▪ Could be detrimental to some species
▪ Reduction in salinity of lake water and soils	▪ Beneficial
▪ Spread of exotic weeds – grey willow	▪ Detrimental
▪ Low, stable lake levels	▪ Beneficial
▪ Changes which affect availability of grasses, i.e. increase in soil salinity or lake surface area	▪ Detrimental
▪ Changes which affect availability of grasses, i.e. increase in soil salinity or lake surface area	▪ Detrimental
▪ Factors which increase abundance of birds, e.g. reduced turbidity	▪ Indirect benefit
▪ Beneficial	
▪ Beneficial	
▪ Factors which affect agricultural vegetation (P) and agricultural herbivores (Q)	

COLIN HILL

12

APPENDICES

CLIVE HOWARD-WILLIAMS NIWA **SCOTT LARNED** NIWA

Appendix A: Water Resource Management Presentation.
Powerpoint presented at the Living Lake Symposium,
Lincoln University, 31 October - 3 November 2007

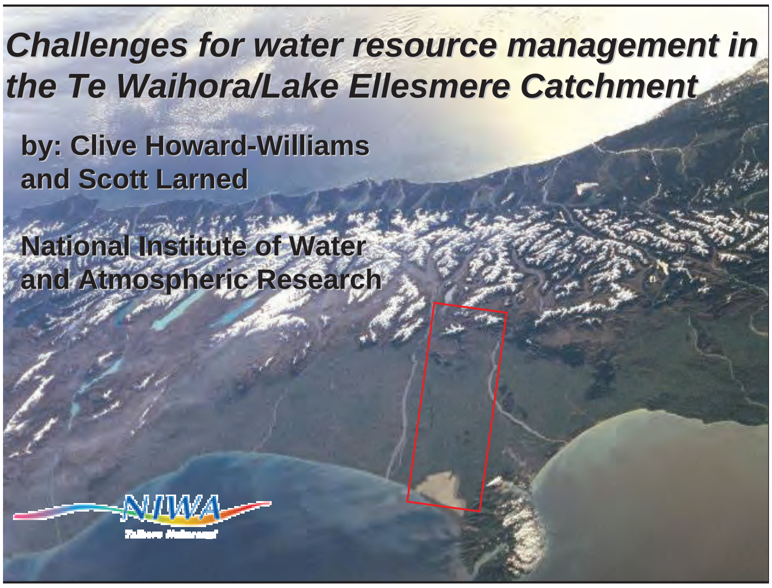
HUGH THORPE Environment Canterbury

Appendix B: Hydrology Presentation.
Powerpoint presented at the Living Lake Symposium,
Lincoln University, 31 October - 3 November 2007

<< 12.1 Appendix A

Water Resource Management Presentation

Clive Howard-Williams and Scott Larned



Challenges for water resource management in the Te Waihora/Lake Ellesmere Catchment

by: Clive Howard-Williams and Scott Larned

National Institute of Water and Atmospheric Research

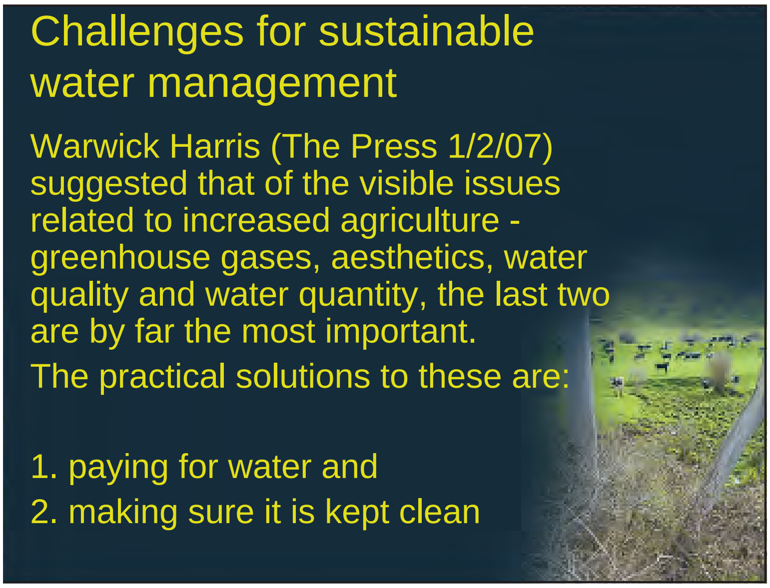
Strategic background

ECAN: Long Term Council Community Plan 2006-16

Key issues for water and ecosystems:

- Stress on water systems
- Allocation limits
- Water Quality (from land-use intensification)
- Partnerships with communities.

Other Government strategies……

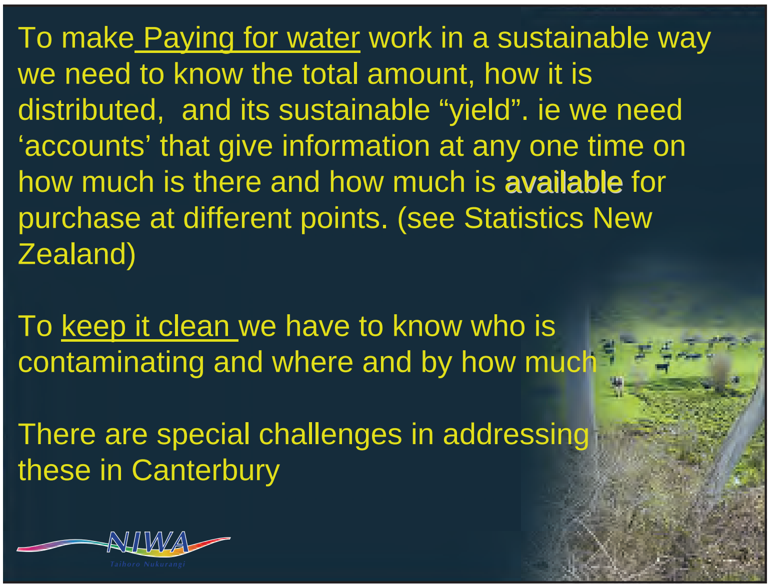


Challenges for sustainable water management

Warwick Harris (The Press 1/2/07) suggested that of the visible issues related to increased agriculture - greenhouse gases, aesthetics, water quality and water quantity, the last two are by far the most important.

The practical solutions to these are:

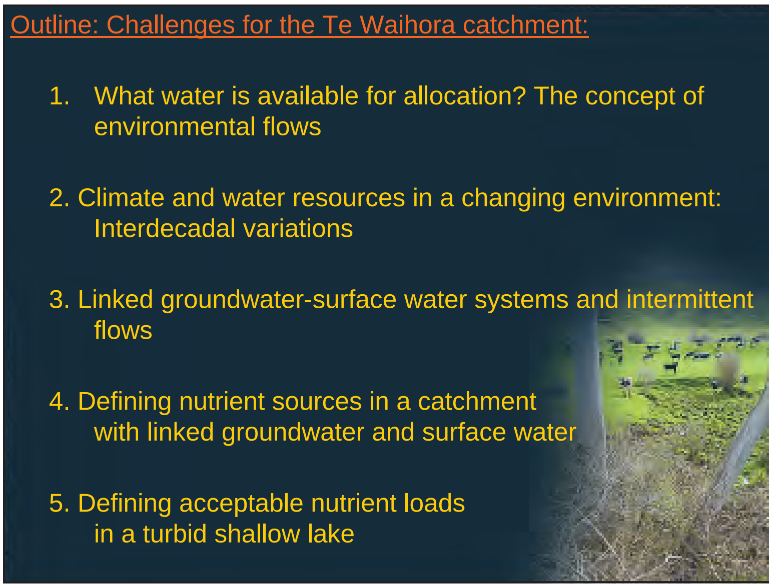
1. paying for water and
2. making sure it is kept clean



To make Paying for water work in a sustainable way we need to know the total amount, how it is distributed, and its sustainable "yield". ie we need 'accounts' that give information at any one time on how much is there and how much is available for purchase at different points. (see Statistics New Zealand)

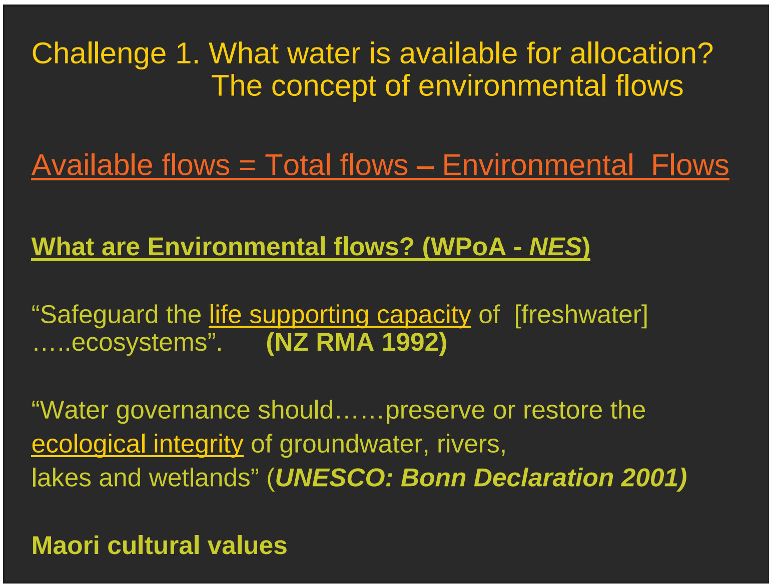
To keep it clean we have to know who is contaminating and where and by how much

There are special challenges in addressing these in Canterbury



Outline: Challenges for the Te Waihora catchment:

1. What water is available for allocation? The concept of environmental flows
2. Climate and water resources in a changing environment: Interdecadal variations
3. Linked groundwater-surface water systems and intermittent flows
4. Defining nutrient sources in a catchment with linked groundwater and surface water
5. Defining acceptable nutrient loads in a turbid shallow lake



Challenge 1. What water is available for allocation?
The concept of environmental flows

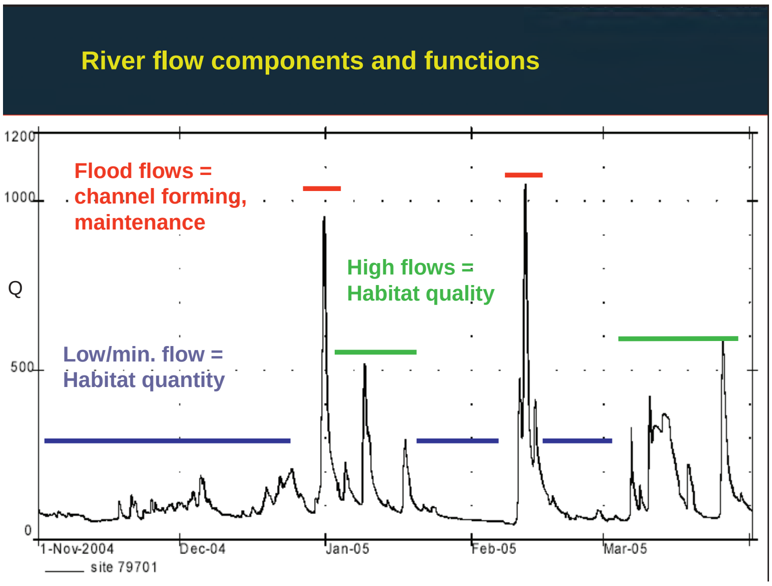
Available flows = Total flows – Environmental Flows

What are Environmental flows? (WPoA - *NES*)

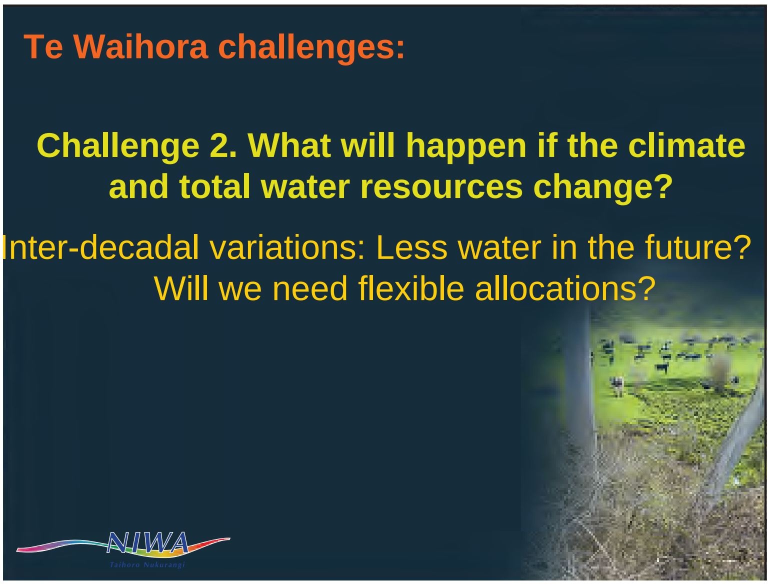
"Safeguard the life supporting capacity of [freshwater] …..ecosystems". **(NZ RMA 1992)**

"Water governance should……preserve or restore the ecological integrity of groundwater, rivers, lakes and wetlands" (***UNESCO: Bonn Declaration 2001)***

Maori cultural values



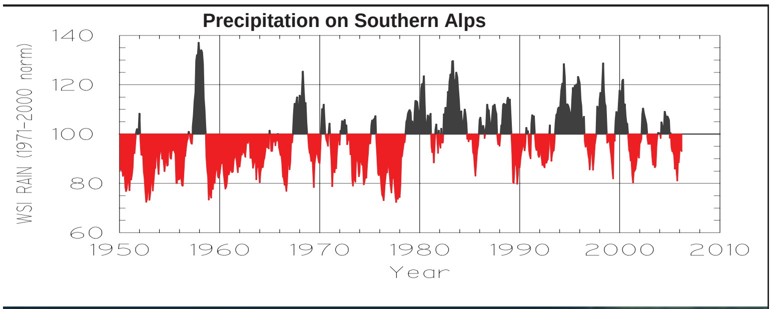
River flow components and functions



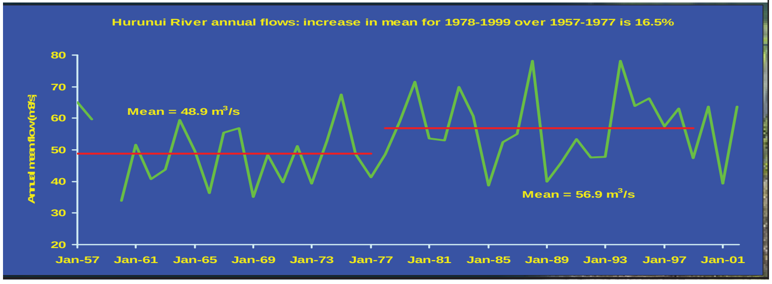
Te Waihora challenges:

Challenge 2. What will happen if the climate and total water resources change?

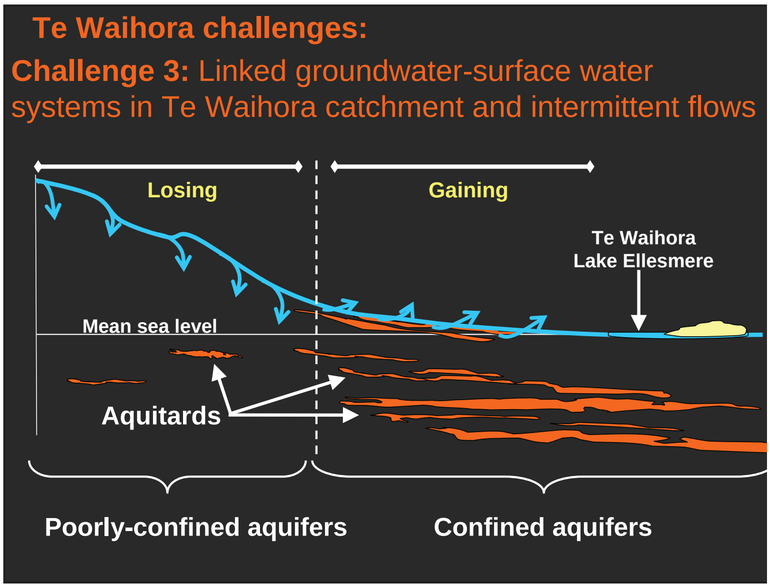
Inter-decadal variations: Less water in the future?
Will we need flexible allocations?



Precipitation on Southern Alps

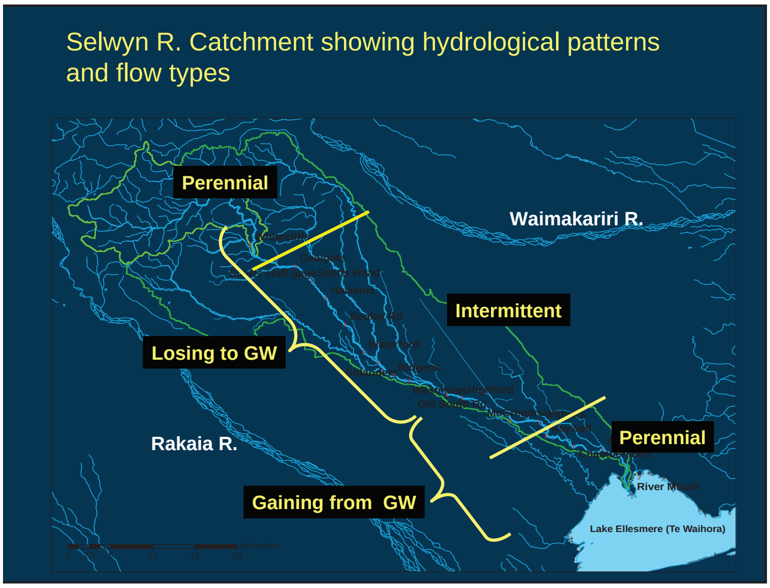


Hurunui River annual flows: increase in mean for 1978-1999 over 1957-1977 is 16.5%



Te Waihora challenges:

Challenge 3: Linked groundwater-surface water systems in Te Waihora catchment and intermittent flows



Selwyn R. Catchment showing hydrological patterns and flow types

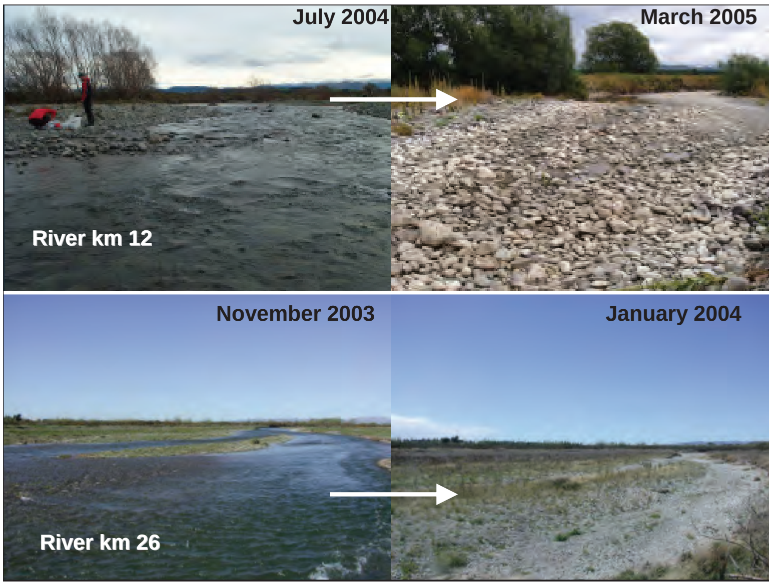
Spring-fed lowland tributaries

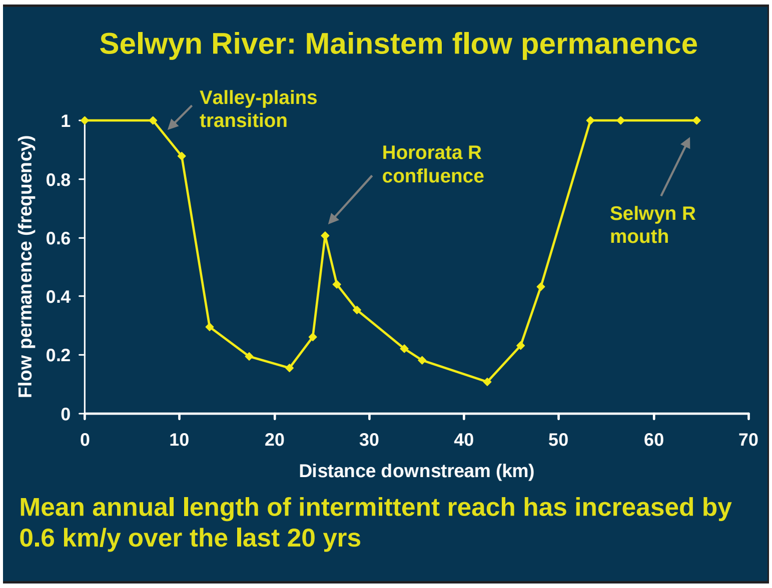
L-II River

Harts Creek

Selwyn River: mix of spring fed and hill fed water sources

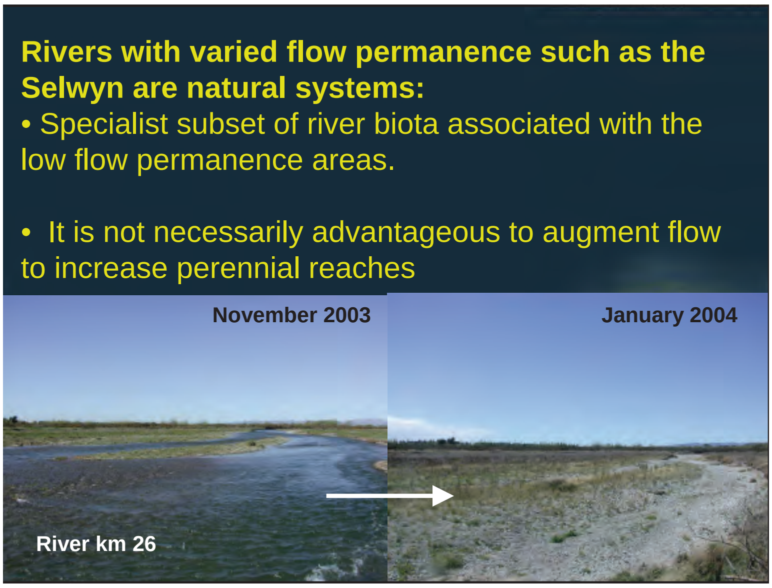
Intermittent flows





Selwyn River: Mainstem flow permanence

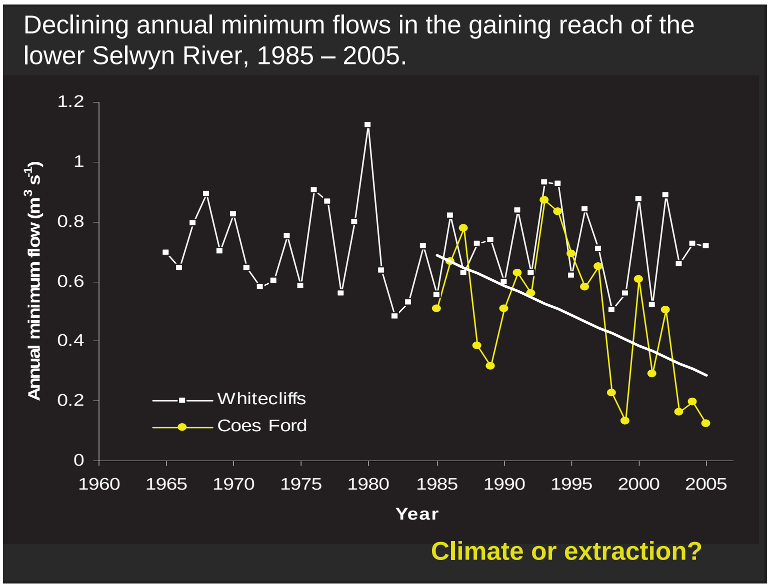
Mean annual length of intermittent reach has increased by 0.6 km/y over the last 20 yrs



Rivers with varied flow permanence such as the Selwyn are natural systems:

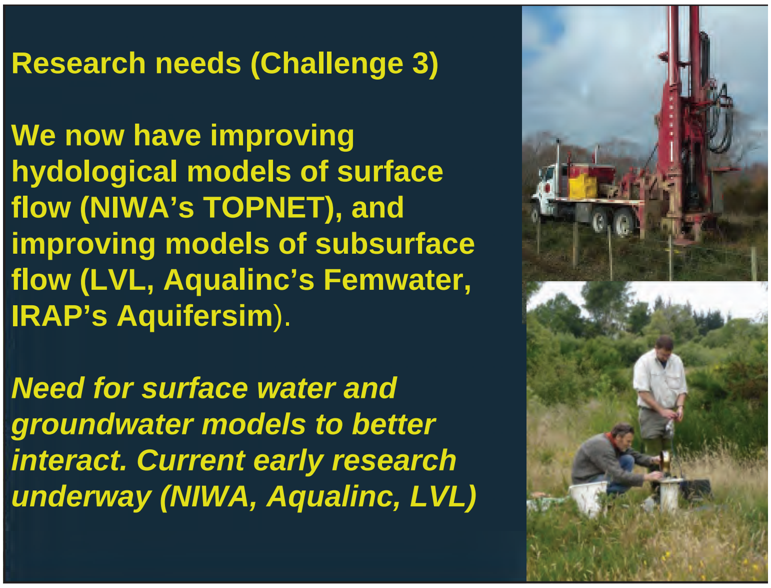
- Specialist subset of river biota associated with the low flow permanence areas.

- It is not necessarily advantageous to augment flow to increase perennial reaches



Declining annual minimum flows in the gaining reach of the lower Selwyn River, 1985 – 2005.

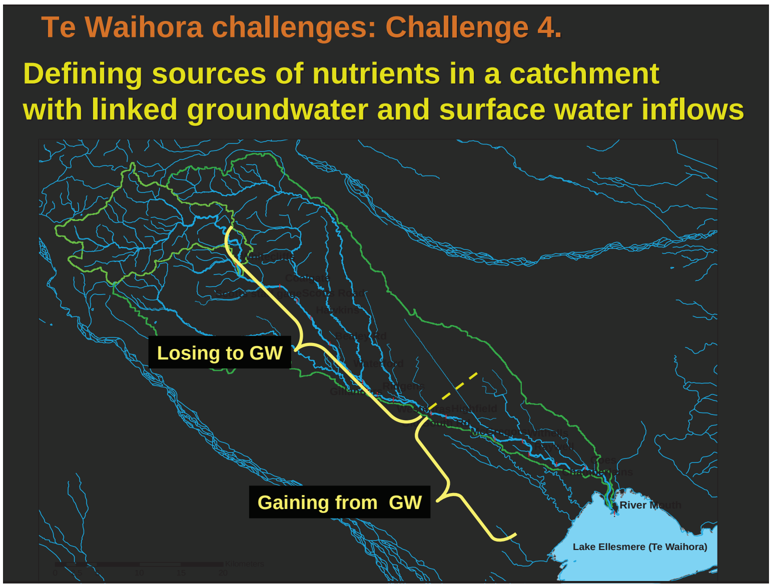
Climate or extraction?



Research needs (Challenge 3)

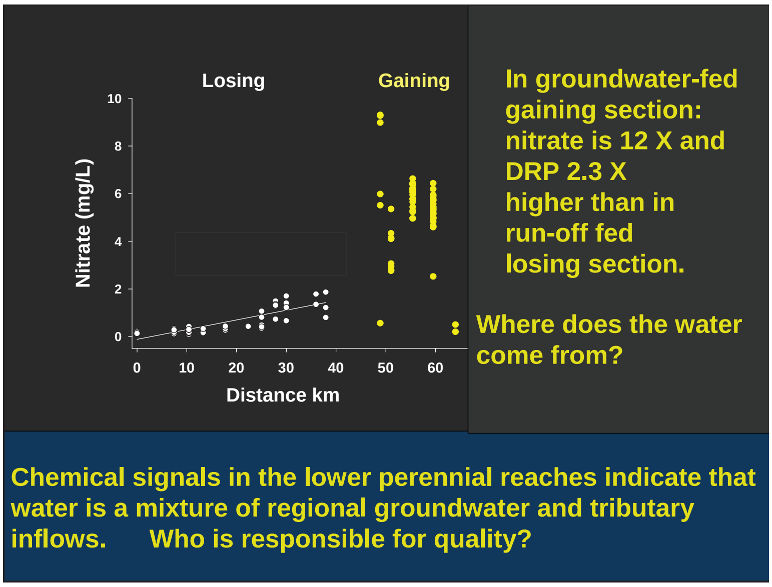
We now have improving hydrological models of surface flow (NIWA's TOPNET), and improving models of subsurface flow (LVL, Aqualinc's Femwater, IRAP's Aquifersim).

Need for surface water and groundwater models to better interact. Current early research underway (NIWA, Aqualinc, LVL)



Te Waihora challenges: Challenge 4.

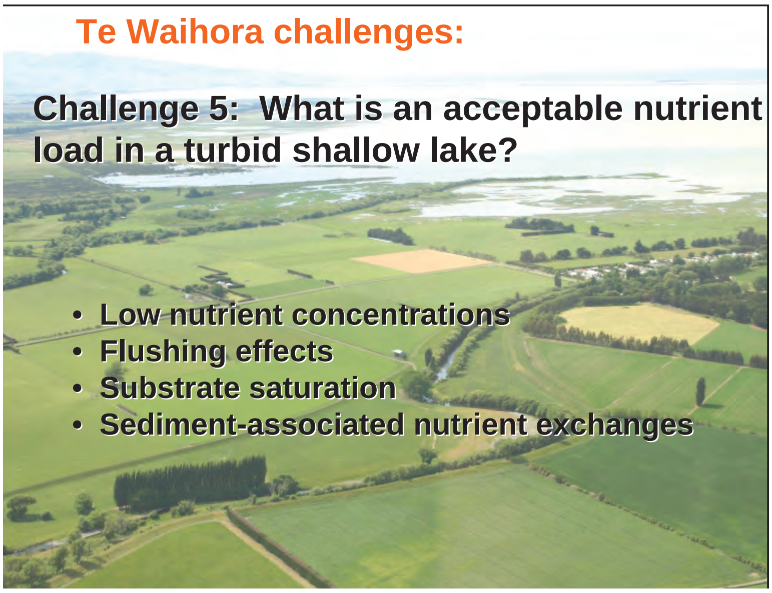
Defining sources of nutrients in a catchment with linked groundwater and surface water inflows



In groundwater-fed gaining section: nitrate is 12 X and DRP 2.3 X higher than in run-off fed losing section.

Where does the water come from?

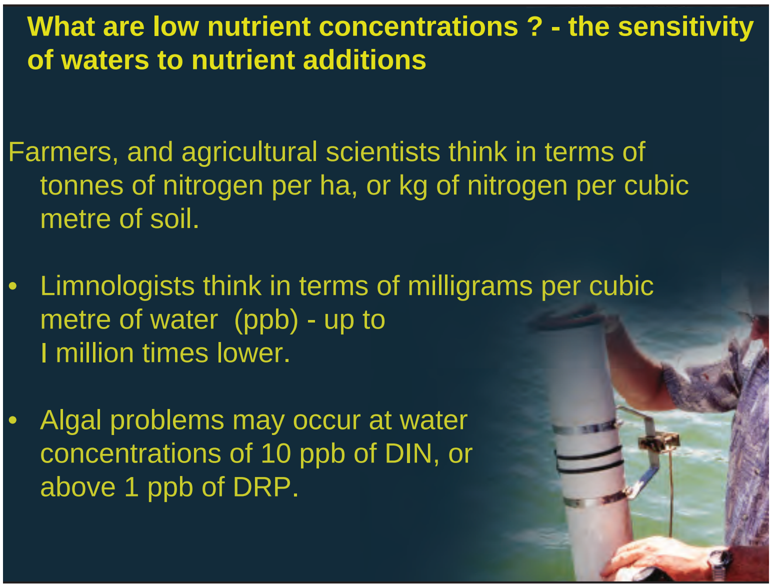
Chemical signals in the lower perennial reaches indicate that water is a mixture of regional groundwater and tributary inflows. Who is responsible for quality?



Te Waihora challenges:

Challenge 5: What is an acceptable nutrient load in a turbid shallow lake?

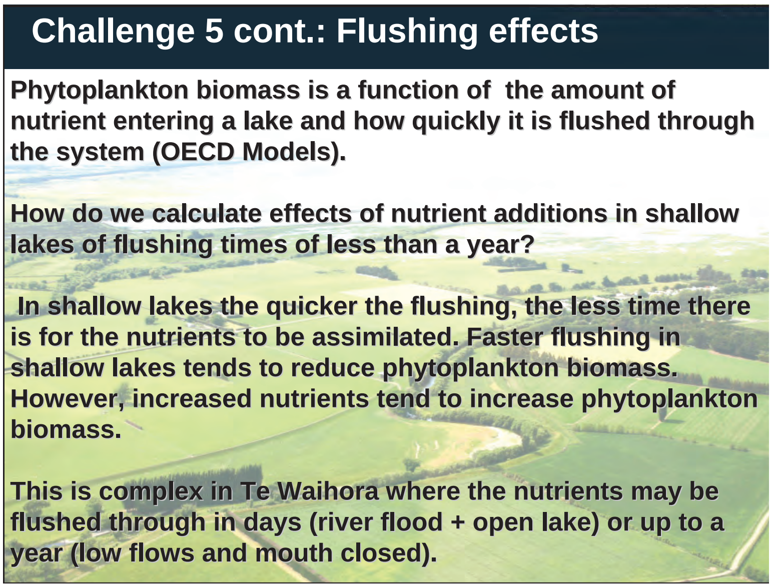
- Low nutrient concentrations
- Flushing effects
- Substrate saturation
- Sediment-associated nutrient exchanges



What are low nutrient concentrations ? - the sensitivity of waters to nutrient additions

Farmers, and agricultural scientists think in terms of tonnes of nitrogen per ha, or kg of nitrogen per cubic metre of soil.

- Limnologists think in terms of milligrams per cubic metre of water (ppb) - up to I million times lower.
- Algal problems may occur at water concentrations of 10 ppb of DIN, or above 1 ppb of DRP.



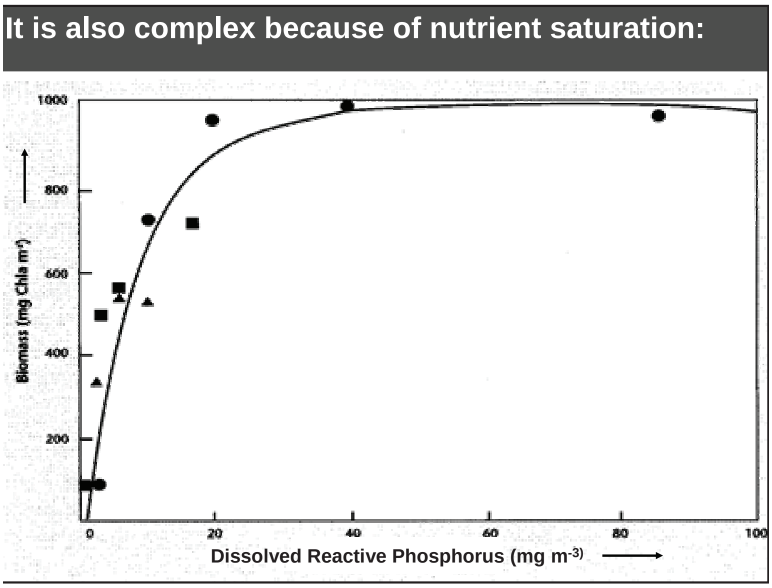
Challenge 5 cont.: Flushing effects

Phytoplankton biomass is a function of the amount of nutrient entering a lake and how quickly it is flushed through the system (OECD Models).

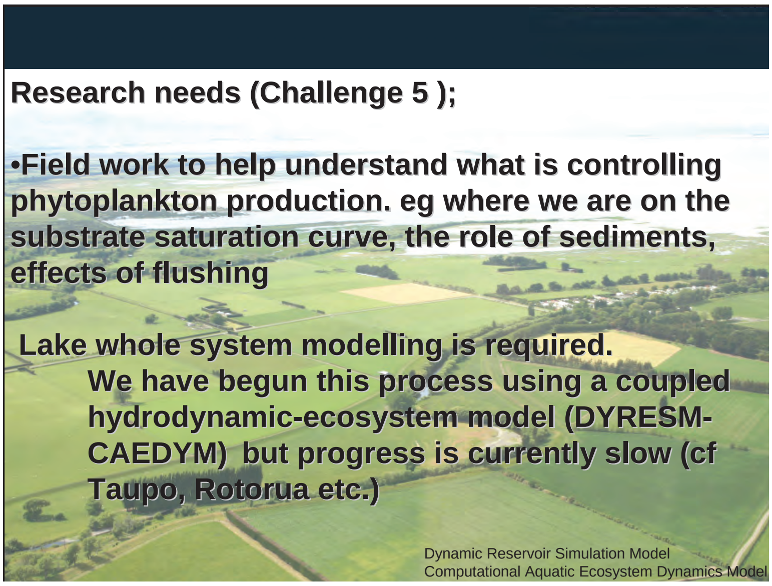
How do we calculate effects of nutrient additions in shallow lakes of flushing times of less than a year?

In shallow lakes the quicker the flushing, the less time there is for the nutrients to be assimilated. Faster flushing in shallow lakes tends to reduce phytoplankton biomass. However, increased nutrients tend to increase phytoplankton biomass.

This is complex in Te Waihora where the nutrients may be flushed through in days (river flood + open lake) or up to a year (low flows and mouth closed).



It is also complex because of nutrient saturation:

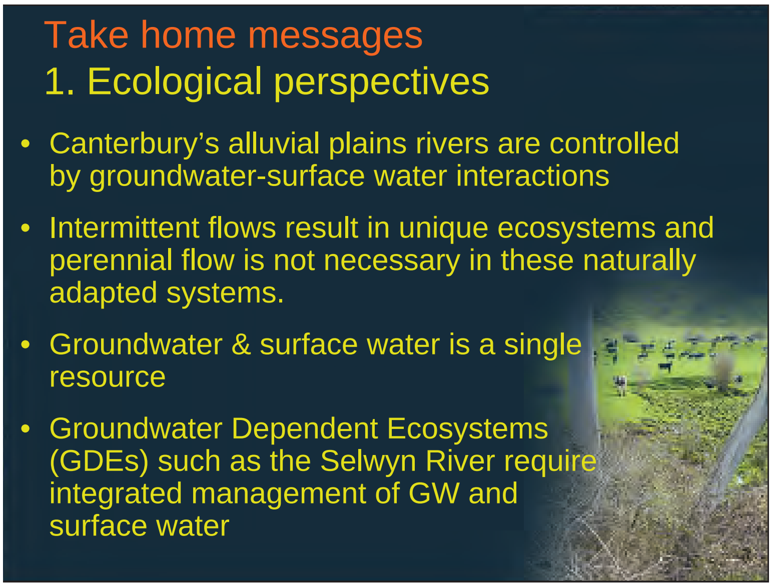


Research needs (Challenge 5);

•Field work to help understand what is controlling phytoplankton production. eg where we are on the substrate saturation curve, the role of sediments, effects of flushing

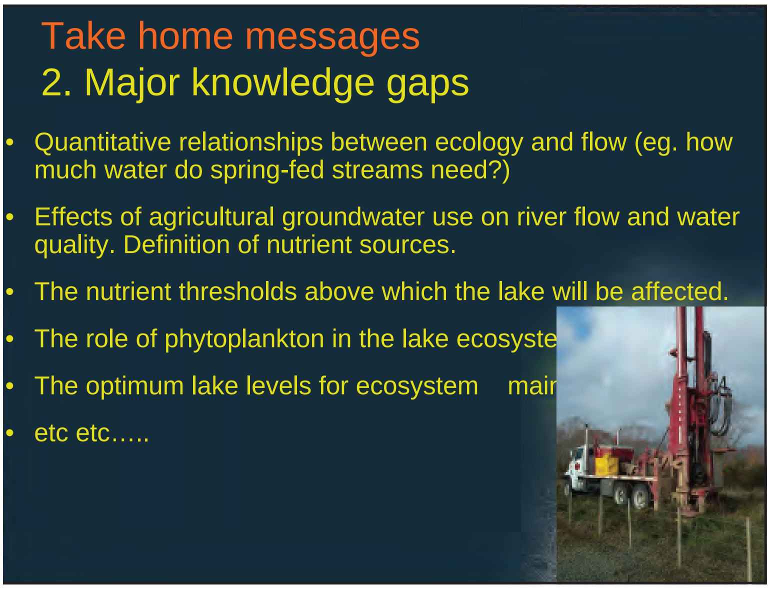
Lake whole system modelling is required.
We have begun this process using a coupled hydrodynamic-ecosystem model (DYRESM-CAEDYM) but progress is currently slow (cf Taupo, Rotorua etc.)

Dynamic Reservoir Simulation Model
Computational Aquatic Ecosystem Dynamics Model



Take home messages
1. Ecological perspectives

- Canterbury’s alluvial plains rivers are controlled by groundwater-surface water interactions
- Intermittent flows result in unique ecosystems and perennial flow is not necessary in these naturally adapted systems.
- Groundwater & surface water is a single resource
- Groundwater Dependent Ecosystems (GDEs) such as the Selwyn River require integrated management of GW and surface water



Take home messages
2. Major knowledge gaps

- Quantitative relationships between ecology and flow (eg. how much water do spring-fed streams need?)
- Effects of agricultural groundwater use on river flow and water quality. Definition of nutrient sources.
- The nutrient thresholds above which the lake will be affected.
- The role of phytoplankton in the lake ecosyste
- The optimum lake levels for ecosystem main
- etc etc…..

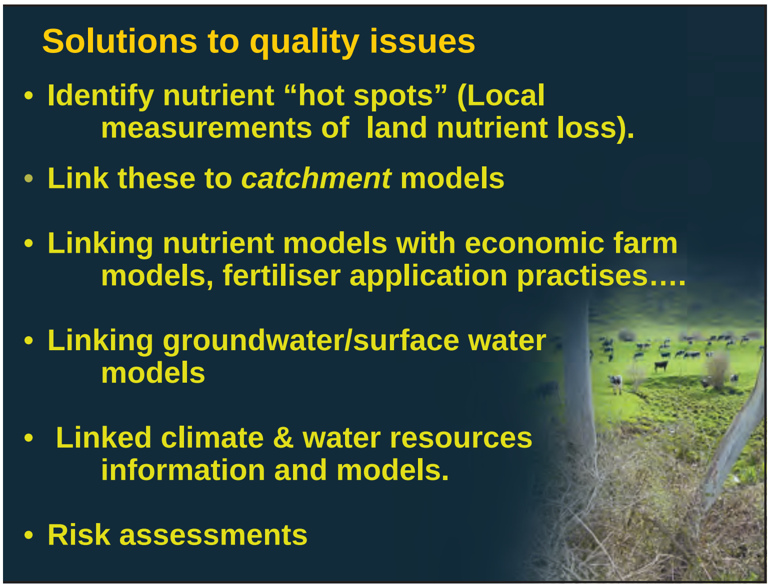
Predictions for the future?

Increase in intensity of agriculture
vs.
Increase in mitigation and improved practices

Will they balance ???

THE END

Selwyn River at Highfield Rd Ford
19 December 2006



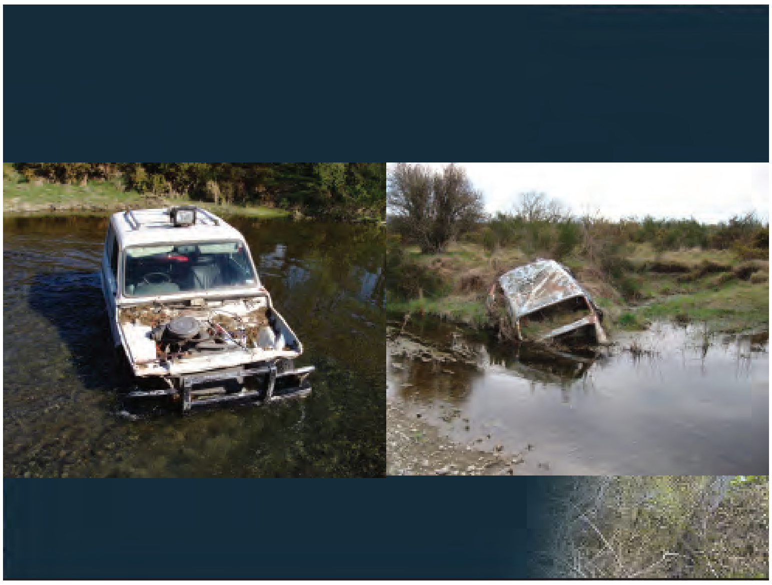
Solutions to quality issues

- Identify nutrient "hot spots" (Local measurements of land nutrient loss).
- Link these to *catchment* models
- Linking nutrient models with economic farm models, fertiliser application practises….
- Linking groundwater/surface water models
- Linked climate & water resources information and models.
- Risk assessments

Solutions to quality issues (cont.)

On farm/forest:

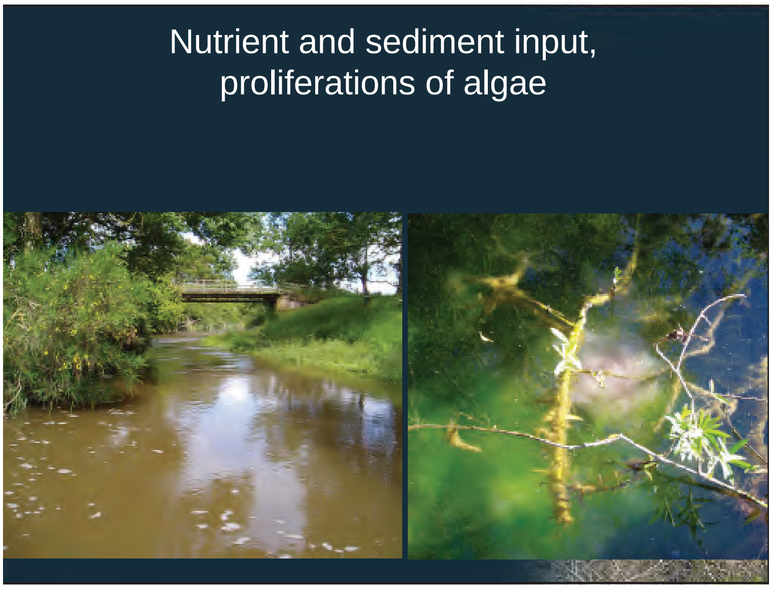
- Riparian and farm drain management to maximise nutrient retention.
- Slow release fertilizers.
- Nitrification inhibitors.
- Constructed wetlands and Advanced Pond Systems.
- Data sets of quality assured information at appropriate time scales.
- Community driven water resource initiatives



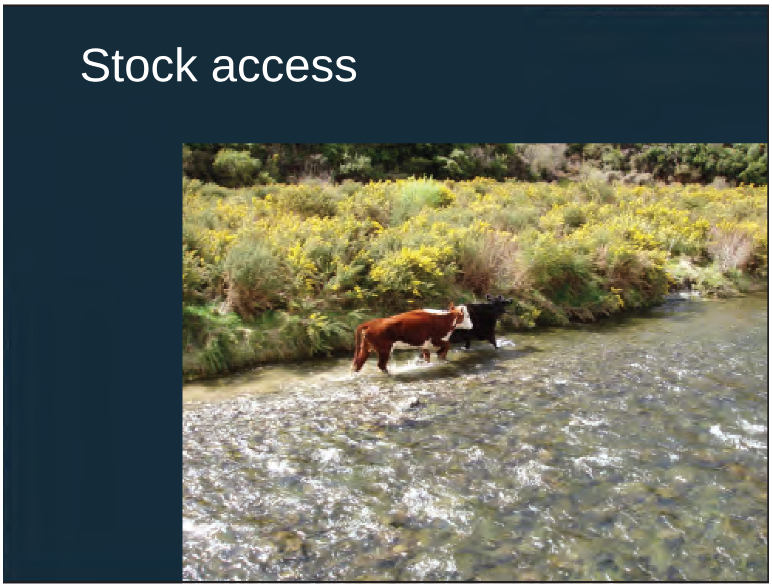
Flood control & river works

Gravel extraction

Sediment starvation affects downstream river channels and lake deltas. Research urgently needed on sediment mass balance



Nutrient and sediment input, proliferations of algae



Stock access

12.2 Appendix B

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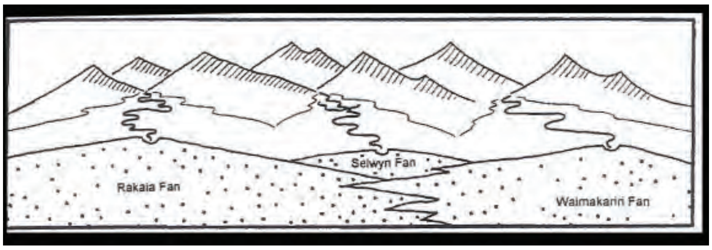
Hydrology Presentation

Hugh Thorpe

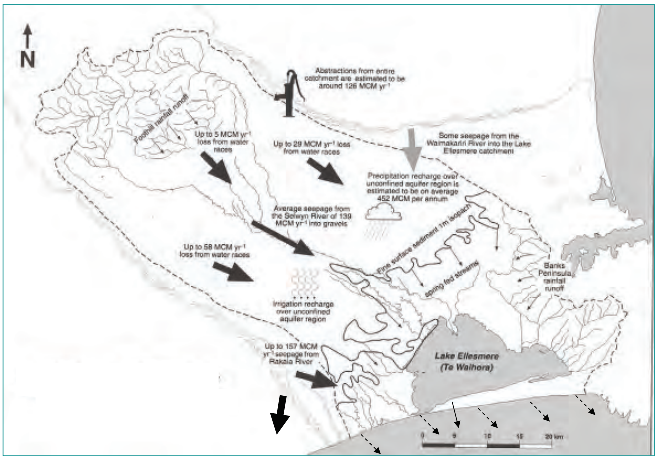
THE HYDROLOGY OF TE WAIHORA / LAKE ELLESMERE CATCHMENT.

Hugh Thorpe



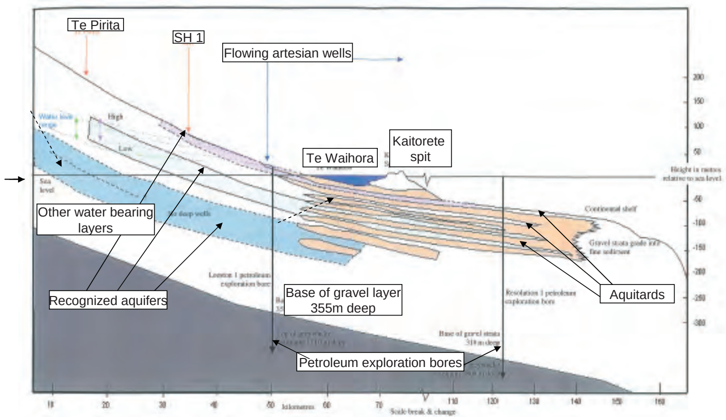
Elements of the groundwater balance in the Te Waihora/Ellesmere catchment

(Taylor (ed.) 1996)



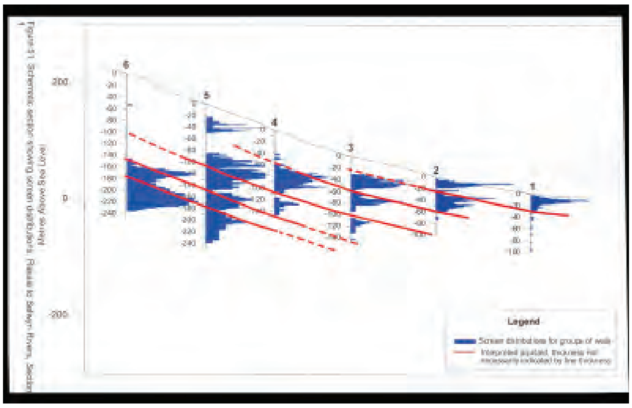
Geological cross-section from Te Pirita to Kaitorete spit showing aquifer and aquitard structure.

(Wiliams 2006)



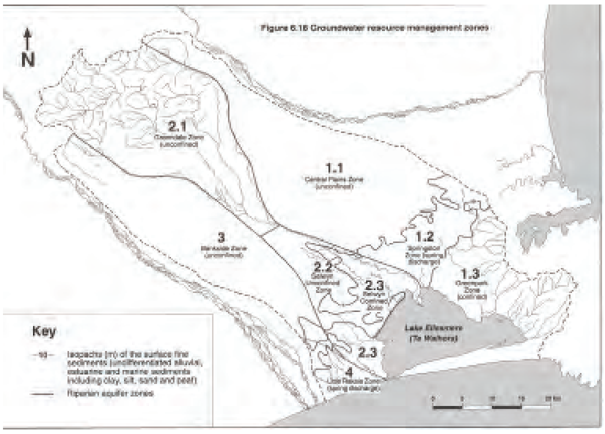
Schematic X-section showing well screen distributions and hence aquifer sequence in Rakaia-Selwyn zone.

(Davey 2006)



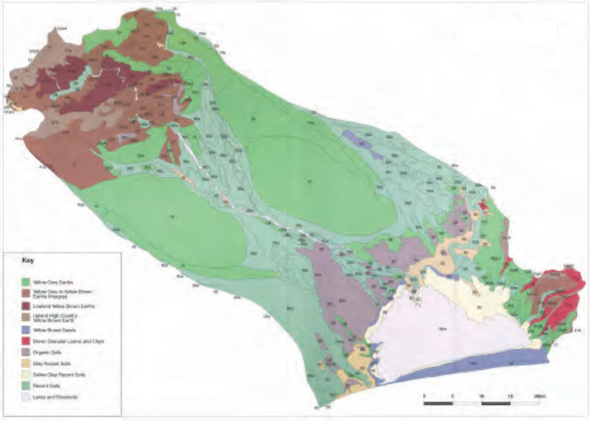
Groundwater resource management zones.

Taylor (ed.) 1996)

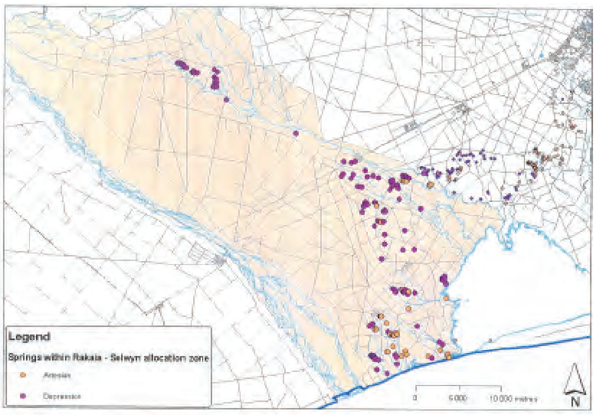


Distribution of soils in the Ellesmere catchment.

(Taylor (ed.) 1996)

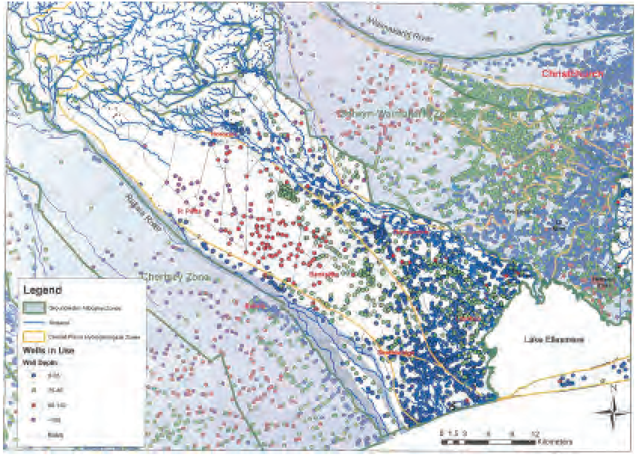


Springs within the Te Waihora /Lake Ellesmere catchment



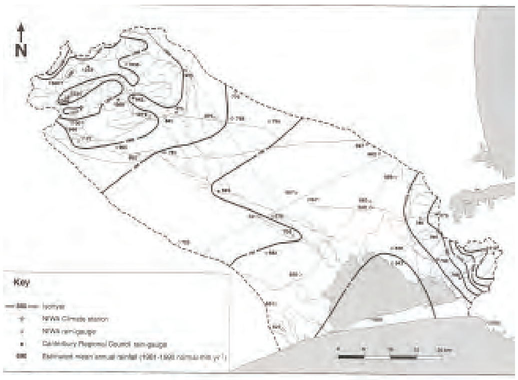
Well distribution in the Te Waihora / Lake Ellesmere catchment.

(Williams 2006)



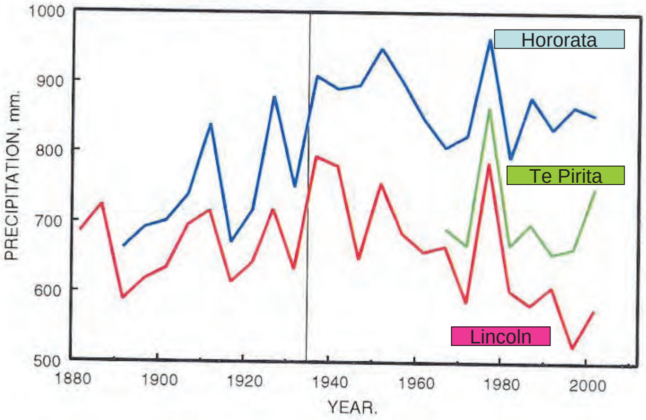
Mean annual rainfall (mm) in Te Waihora/Lake Ellesmere catchment

(Taylor (ed) 1996)



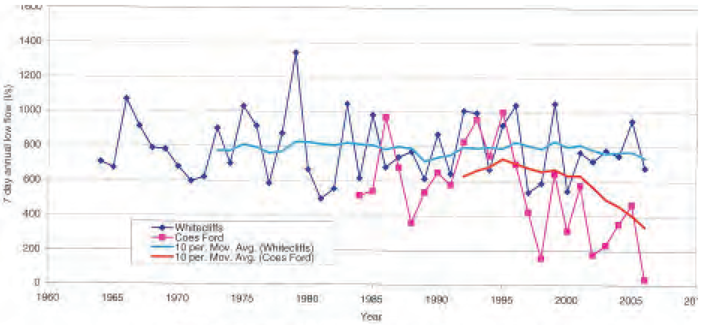
Pentads of means of precipitation

(Larsen 2006)



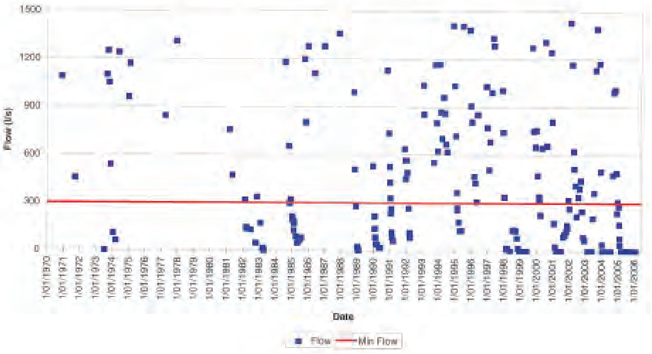
Selwyn River:
7-day annual low flows at Whitecliffs and Coes Ford.
1964-2006

(Horrel 2006)



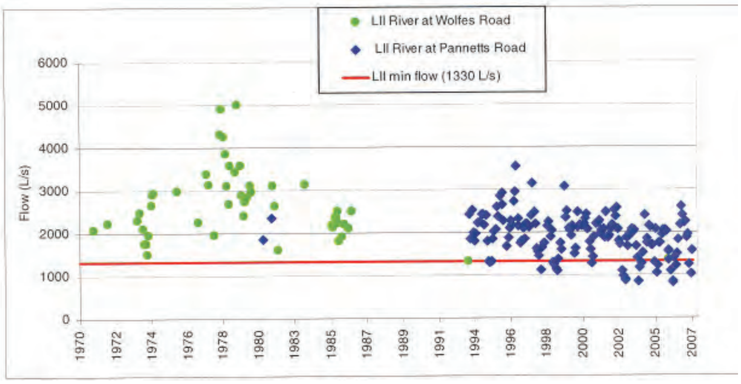
Irwell River spot gaugings and minimum flow 1970-2006

(Horrell 2006)



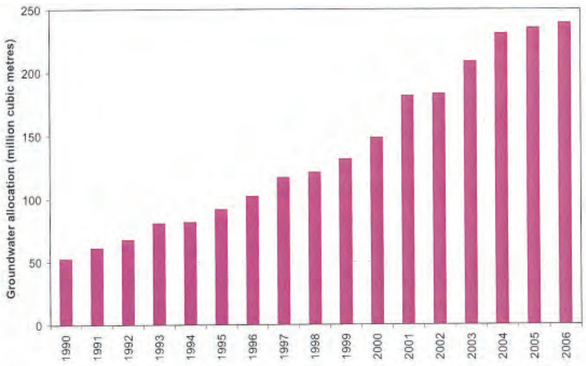
Gauged flows for two sites on the LII River 1970-2007

(Gabites 2007)

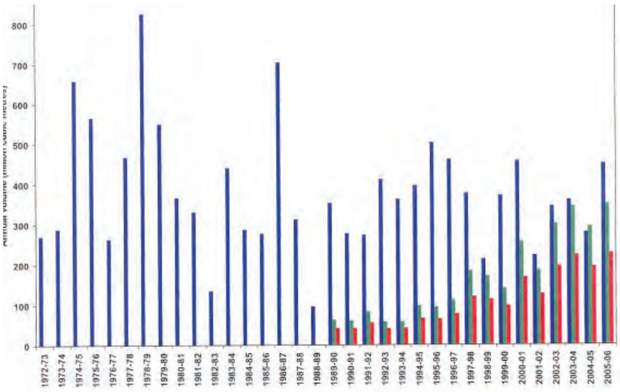


Annual allocation volume from groundwater in the Rakaia-Selwyn zone: 1990-2006

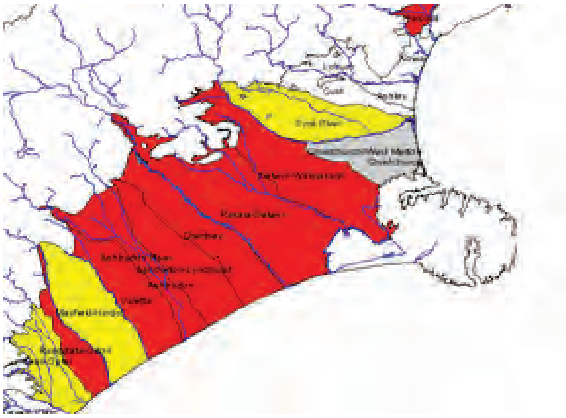
(Scott 2006)



Calculated land-surface recharge (blue): 1972-2006
Estimated irrigation demand (green) and actual use (red) since 1989/1990
(Scott 2006)



Environment Canterbury's
groundwater allocation zones



SUMMARY

- The water balance of the catchment is still somewhat imprecise.
- Stream flows have been measured and observed to be decreasing over the last decade.
- The main reason for such decreases is climate variability.
- Irrigation takes from groundwater have increased almost 5-fold since 1990.
- The rainfall over this period has not been especially low.
- Statistical analysis of rainfall, and flows at Coes Ford strongly suggest that the low flows are exacerbated by irrigation takes.
- The arbitrary allocation by Ecan of 50% of assessed recharge as available for taking should be reconsidered. It may be too high **in the Te Waihora catchment.**
- The proposed review of present consents should be supported.

Te Waihora/Lake Ellesmere is a large coastal lake, intermittently open to the sea. It is highly regarded for its conservation and related values, some of which are of international significance. Its function as a sink for nutrients from its large predominantly agriculturally based catchment, currently undergoing accelerated intensification, is also recognised, at least implicitly. It is the resulting conflict from these value sets which is mainly responsible for the ongoing debate about the future of the lake.

This book serves to quantify the nature of this debate by documenting changes to lake values, both over time and spatially. It provides a standardised approach to reporting these changes, set against indicators that are value-specific. Ultimately, it provides a template for thinking about future management scenarios for the lake and its environs. Given this approach the book ultimately serves as a resource for helping understand the ever-changing and current and possible future states of the lake, under a variety of management requirements and implications.