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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Lincoln University · Environment Canterbury

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SHELLEY McMURTRIE

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SHELLEY McMURTRIE

01 INTRODUCTION

SHUTTERSTOCK

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.

[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.

SHIRLEY HAYWARD

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CURRENT STATE and future management

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

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

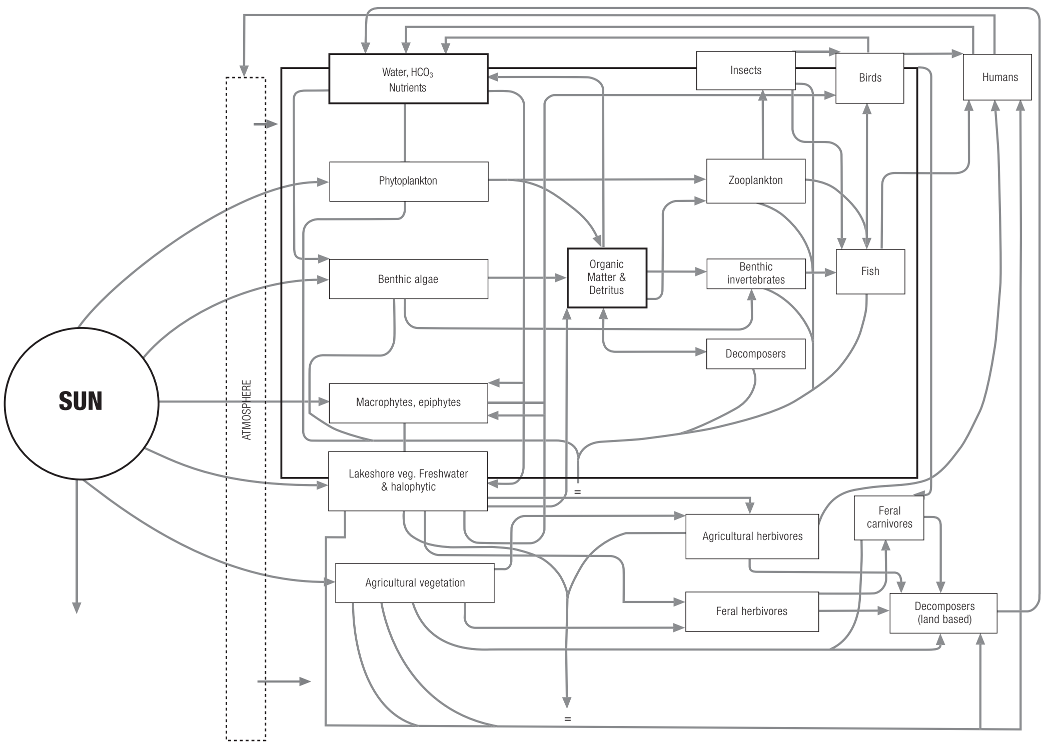

FIGURE 1. Model of the Te Waihora/Lake Ellesmere energy flows (adapted from Davis *et al.* 1996).

[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).

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/

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)

[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			

[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.

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’

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

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

[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

[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] ▪ 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 ▪ Higher average lake level [native vegetation, swampbirds, fish habitat]	▪ Maintain opening and closing regimes ▪ Investigate permanent controlled outlet and if feasible implement [fisheries, wildlife, vegetation]
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 ▪ Begin significant revegetation programmes [vegetation] ▪ Negotiate changed farming practices to achieve conservation outcomes ▪ Acquire and manage remaining lake edge farmlands	▪ Maintain benefits from all short-term actions and ▪ Undertake willow control in key areas [vegetation, wildlife] ▪ Protect key riparian habitats [fish, wildlife, vegetation] ▪ Investigate the re-introduction of brown teal for conservation and Ngāi Tahu cultural harvest purposes ▪ Implement changed farming practices to achieve conservation outcomes	▪ Continue all short and medium term actions where beneficial ▪ Re-introduce brown teal for conservation and Ngāi Tahu cultural harvest purposes [Wildlife, The Ngāi Tahu Values]
Catchment management	▪ Active programme to maintain current and where possible increase stream flows and groundwater levels (restorative streams consents review programme) ▪ Develop and implement a nutrient management programme	▪ Restore flows and groundwater levels as further consents renewed and/or community irrigation schemes developed ▪ mplement further nutrient reduction measures	▪ Maintain restored flows and groundwater levels ▪ 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-

[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.

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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.

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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	▪ May increase abundanc
▪ Reduction in turbidity, salinity and desiccation	▪ 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)	

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.