Ministry for the
Environment
Manatū Mō Te Taiao

Lake Level Management

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Acknowledgements

Background

The *Lake Managers' Handbook* was published in 1987 (Vant 1987) and is still widely used and highly regarded by lake managers and others involved in water management. The *Handbook* was designed to guide investigations into lake ecosystems, to interpret the result of such investigations, and to help managers to assess their management options. This guide updates and expands Chapter 22 from the *Handbook*, which dealt with lake levels and lakeshore erosion (Mark and Kirk 1987) and incorporates recent work on marginal vegetation that was originally covered in Chapter 10 of the *Handbook* (Johnson 1987).

Since 1987 there has been a considerable increase in our knowledge of the physical and biological processes in lakes and on lake shores, particularly through government-funded research targeted at understanding and predicting the effects of human activities. This has underpinned a number of assessments of environmental effects (AEEs) for various consents under the Resource Management Act 1991 (RMA). Unfortunately, much of this information has not been disseminated to all those involved in lake management, nor to the wider public. These studies have incorporated a greater range of lakes than those discussed in the 1987 *Handbook*, and have considerably improved our ability to predict adverse effects and suggest mitigation options.

This guide brings together the new information on lake-level fluctuations, most of it previously only available in consultancy reports, in a form suitable for lake managers. We begin by outlining the major issues, the most important physical and biological processes, and the biological communities that are likely to be impacted by fluctuating lake levels (section 1). We then discuss the effects of lake-level regimes on these processes (section 2). Section 3 looks at issues and requirements of the RMA, and provides a checklist for assessing environmental effects, while section 4 raises a number of management issues. Section 5 covers monitoring requirements and recommendations, and finally section 6 presents a discussion on new approaches and developments in assessing impacts.

Throughout the guide New Zealand case studies are used to demonstrate different approaches used on the variety of lakes that have been studied.

Introduction

New Zealand's lakes are a highly valuable resource. Focal points for tourism, they attract visitors who appreciate their natural beauty, or who come to fish, swim or explore. They have long been important to Maori as a food resource and for their cultural associations. And they have attracted people to live at their edges: seven large urban areas are situated on lakeshores, at Taupo, Rotorua, Cromwell, Hawea, Wanaka, Queenstown and Te Anau.

Lakes have also been put to work – for hydro-electric generation, for water storage for irrigation schemes and for flood control. There are now over 60 lakes, dams and reservoirs managed for hydro-electric storage in New Zealand, and they provide 78% of the country's electricity demand. Six of the seven lakes mentioned above are also used for hydro-electric storage and operation. Recent deregulation of the electricity market and the sale of a number of government-owned power stations to private companies has resulted in a need for greater flexibility in operation levels to meet peak demands and the spot market.

However, using lakes in these ways has altered lakeshores through artificially manipulating lake levels. The lake edge is the interface between water and land. This is often a region of dynamic physical processes, and high biodiversity and productivity, serving as a crucial habitat for terrestrial and aquatic plants and many invertebrates, fish and birds during all or part of their life cycles. The littoral zone – the region inhabited by benthic-rooted[1] aquatic plants, is often the first part of a lake to suffer the effects of human activity. This zone is particularly important in New Zealand's highly valued oligotrophic lakes, where macrophyte beds extend down to depths of over 20 m (Howard-Williams et al. 1987) and in some cases 36 m; for example, Lake Coleridge (Clayton 1984).

Benthic vegetation can underpin the biological productivity of lakes such as Coleridge (James et al. 1998) and Otamangakau (Stark and Dedual 1997), so that any activity that affects the littoral zone can have a significant ecological effect. The degree of impact depends on a number of factors, including both the range and rate of change, and the duration and timing of lake-level fluctuations. Each of these factors, under extreme high or low lake levels, will affect different parts of the ecosystem, and these are discussed in detail in later sections.

Wave action and wave-induced currents work on lakeshores in much the same way as on oceanic beaches, but with important differences in magnitude. The size of waves and the energy within them is a function of the available fetch (distance of water that wind travels over), wind speeds and wind durations on the lake. Bigger fetches, higher wind speeds and longer durations of wind events will all lead to larger waves. Just where the wave activity works on the shore is a direct function of the lake level, while lake level can also significantly alter the fetch length.

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[1] Rooted in the lake bed.

Lake-level fluctuations can lead to varied responses at the shore, from short-term adjustments to a quasi-equilibrium shoreline, to inducing a change in the long-term sediment budget of a shore. Significantly, erosion can – but will not always – result from either prolonged low or high lake levels. Storms when lake levels are low can move sediment from the active beach and nearshore to offshore and away from the influence of constructive wave action. Storms when lake levels are high can result in waves eroding the base of hillslopes, initiating mass movement of slope material.

It is important to note that the principles of the physical processes that control the stability of high-energy oceanic beaches are applicable to lakeshores. In particular, process–response and sediment-budget models can be adapted for lakeshore situations.

Over time, lakes develop an equilibrium between variations in water level, wave patterns and physical and biological features of their shoreline. Lake-level changes under natural conditions will depend on rainfall, spring snow melt (in some cases), catchment topography and outlet characteristics. Manipulating water levels (upward) to maximise storage capacity and (downward) during peak electricity demand has altered the natural regime of several lakes. In extreme cases, such as Lake Hawea, variations have been as much as 21.9 m compared with 2.86 m before controls (Mark 1987), although in recent years fluctuations have been much smaller in order to mitigate adverse effects. For Lake Pukaki, water-level management has taken two forms: raising the lake by over 33 m, and utilising an operating range of 13.8 m.

Any significant change to a lake's level, in terms of extent or duration, will affect not only the lake's physical processes, but also (either directly or indirectly) its biological productivity (see Figure 1). Direct effects on the biological communities include slumping, which can impact on terrestrial and aquatic vegetation, and physical disruption through changes to the zone affected by wave activity. Indirect effects include the reworking of substrates (which can enhance or restrict colonisation by vegetation, and which in turn depends on silt accumulation to establish roots), and alteration of habitats important for aquatic fauna.
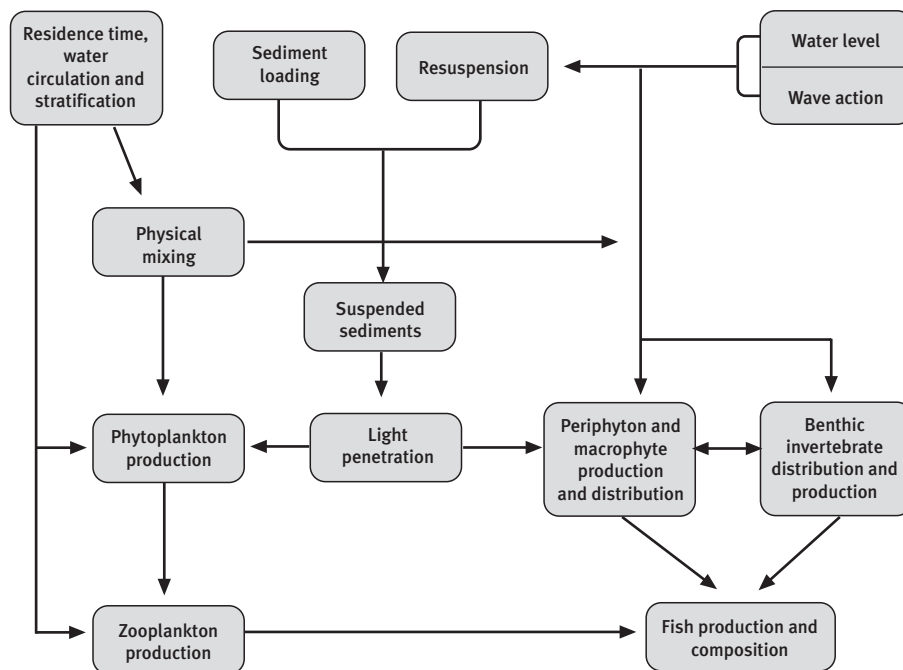
Figure 1: How changing lake-level conditions affect physical processes, and their impact on the food web of lakes.

Physical processes

Lake beaches are dynamic and rapidly adjust their form in response to changes in lake level and the wave environment. The shorelines of New Zealand lakes are composed of a range of geomorphological types – from hard, erosion-resistant rock to highly erodible fine silts and muds. In between are less-resistant rock types, such as mudstone and sandstone, and beaches of sands, gravels and mixtures of sediment sizes. Because of this variation, lake beaches have a wide range of sediment particle sizes, and so movement of the sediment is a function of sediment size and the energy of the waves – larger sediments require greater energy to set them in motion. The result of sediment movement can be erosion (whether by loss of sediment from the visible part of the beach, or by landward retreat of the beach as a whole with no loss of volume); accretion, by the beach gaining volume or moving lakeward; or a quasi-stable shore, where the beach responds to changes in the wave environment by changing shape or form but without a long-term change in beach position.

In addition to wave activity, lakeshores are subjected to fluctuating water levels due to natural variations in rainfall and catchment runoff, or to human manipulation of the inputs to – and (more often) the outputs of water from – the lake for hydro-electric power generation, irrigation or flood control. Kirk (1988) observed that knowledge of lake-level fluctuations can help identify:

- the base level of wave action – this shows the depths to which erosion, transportation and deposition of sediments can occur under waves

- the width of the nearshore that can be traversed by waves

- any seasonal trends.

The last point should also be examined in relation to any seasonality of strong winds.

Much of the research on lakeshore processes has been carried out on the Great Lakes. This work was largely prompted by shoreline erosion during periods of high lake levels (Davidson-Arnott and Askin 1980; Davidson-Arnott 1989). In New Zealand the focus has been on the alpine and glacial lakes of the South Island, and has concerned processes and morphological change on mixed sand and gravel beaches.[2] A small amount of research has been carried out on sandy lake beaches or on cohesive lakeshores.[3] Allan (1998) presents a comprehensive review of material to date.

However, much of the work is unpublished (including Allan 1998), having been carried out as part of thesis research, mainly by students of the Department of Geography, University of Canterbury, or as technical reports on the effects of the operation of lakes for hydro-electric power generation. A number of these reports have examined the effects of power generation operations on the shorelines from existing – or by initiating – beach monitoring programmes. This includes work on the Fiordland lakes (for example, Kirk et al. 1987) and by Hicks et al. (2000) and Kirk and Single (2000) on Lake Taupo, for which there are surprisingly few historical records of beach changes.

Wave activity

The generation of waves on lakes and the height, period and therefore the energy they attain in deep water, are a function of four factors:

- wind velocity

- wind duration

- length of water over which the wind blows (the fetch length)

- water depth.

The relatively small size and the general shape of lakes in New Zealand makes for restricted fetch lengths, which means that the maximum wave height can occur rapidly. In most cases, water depth is not important because the lakes are deep, with narrow, shallow, nearshore zones. On alpine lakes winds are often channelled along the valley axes in which the lakes are formed. The resulting wave environments are bi-directional, with the largest waves acting on the shorelines at the ends of the lakes (Allan 1998).

Wave energy determines the magnitude of work a wave can do in redistributing sediments at the shore. Kirk (1988) found that the wave events that determine beach change are primarily confined to high-energy storms, which occur on average only a few times a year. The type of work – whether erosional or accretional – is a function of wave shape. The short fetches of most New Zealand lakes result in short, steep waves, which are more conducive to erosion at the shore. Beach erosion will therefore occur at very high rates (hours or days) during

[2] See, for example, Pickrill 1985; Kirk and Henriques 1986; MacBeth 1988; Allan 1991; Allan 1998; Kirk et al. 2000.
[3] See, for example, Pickrill 1976; Kirk 1988; Spence 1996.

storms. In contrast, waves that cause accretion tend to be associated with lower-energy conditions, with beach accretion a much slower process, usually taking months or years.

The height of a wave breaking at the shore is governed by the initial wave height as it enters shallow water, and by shoaling of the wave as it crosses the nearshore zone. The amount of sediment transported by waves is controlled by the energy of the wave and the size of the sediment. The direction of transport (whether lakeward or landward) is a function of the wave steepness – the ratio of wave height to wave length. Steeper waves are more likely to transport sediment lakeward, and therefore tend to cause erosion. Pickrill (1976) identified wave steepness values for Lake Manapouri that ranged from 0.01 to 0.08, with a mean of 0.03. Allan recorded average wave steepness values of 0.044 on Lake Pukaki (Allan 1991) and 0.036 on Lake Dunstan (Allan 1998). These values indicate that the waves on alpine lakes can be extremely steep and therefore potentially highly erosional. Conversely, accretion on lake beaches is unlikely to be associated with swell waves, except on large lakes like Taupo, and is more likely to reflect longshore currents and berm construction at the limit of the wave run-up.

The erosive effects of storm waves is enhanced by bottom return currents, which compensate for surface drift currents at the downwind end of a fetch. These currents help to carry sediment, already moved by storm waves, into deeper water. Because of the short-period waves and the narrow zone of shallow water around alpine lakes, waves are not significantly refracted and can break at an oblique angle to shorelines running at an angle to the wind. In 'topographically controlled' alpine lakes, this means the sides of a lake running along a valley axis are subject to strong, long-shore currents. These currents can also cause significant sediment transport.

The degree of wave activity and turbulence has important consequences for physical and biological processes. Biological communities exposed to unusually high turbulence can be significantly disrupted (see section 2). On Lake Ohau, for example, waves are capable of moving substrates up to 10 cm in diameter (Kirk and Henriques 1982). Wave breaker depths have been used in some cases to set minimum operating levels and to minimise scouring of weedbeds. This largely depends on the depth at which orbital velocities (speed of water associated with wave motion) are sufficient to mobilise material. Methods for developing operating levels to minimise the impacts on aquatic flora and fauna will be discussed later (see section 6).

Geomorphology

As we have seen, New Zealand lakeshores present a wide range of sediment particle sizes to the sorting action of waves. However, sediment transport is confined to sections of shore with the greatest exposure to wave action (the longest fetches) and to periods of high-energy wave activity. Fine material is transported onshore and alongshore, while coarser material can remain on the nearshore bed, forming an armour layer of gravels and boulders. Unless there is an external supply of fine transportable gravels (from streams, landslips or updrift sections of shore), the lake beaches will be steep and narrow and have a coarse narrow shelf beneath the water line (Kirk and Henriques 1986).

Irwin (1974) and Pickrill (1976) have noted that although the shores of Lakes Manapouri and Te Anau contain a diverse range of shore types and sediments, the morphology of the beaches on both lakes is similar and can be simplified to three elements (see Figure 2). Three slope units were identified, consisting of the foreshore, the nearshore shelf and the offshore face. This morphology has been found on most lakes around New Zealand, and can be considered to be a general model of the lake beach profile. The foreshore is moderately steep (average slope about 8°), located between mean water level and the upper limit of wave swash. The foreshore grades down to a more gently sloping shelf (average slope about 6°), which extends from mean water level lakeward to a distinct offshore break in the slope. At this break, the slope of the profile plunges steeply at about the angle of repose of the sediments present.
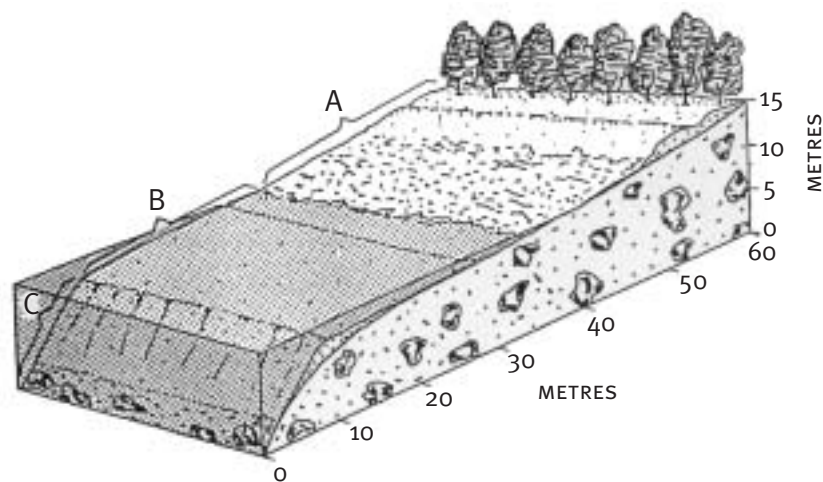
Figure 2: **Typical lakeshore profile developed on glacial moraine at Lakes Manapouri and Te Anau, Fiordland. Regions A, B and C are the foreshore, the nearshore shelf and the offshore face, respectively.**

Source: Reprinted from Pickrill 1976.

Pickrill has shown from studies of Lakes Manapouri and Te Anau that there is a strong correlation between the effective fetch length for wave generation and characteristics of the nearshore shelf. In particular, the relationships between fetch length, width of shelf and depth of water at the lakeward shelf edge are strong. A general principle is that the greater the exposure to wave energy, the wider the shelf and the greater the depth of the outer edge. Pickrill has argued that the development of the nearshore shelf is a function of aggradation of sediments in the nearshore and accretion over the shelf break, which causes the shelf to prograde. Allan (1998) further examined this concept during the development of the Lake Dunstan shoreline after filling of the lake. He concluded that the constructional progradational shelf as described by Pickrill (1976) was one of three types of shore development, and that an erosional shelf could also develop in response to a receding shore and nearshore bed erosion.

The third and most commonly occurring shelf development on Lake Dunstan was a mixture of erosion of the foreshore and aggradation of the nearshore bed. Allan concluded that the antecedent conditions of the shore before filling of the lake

may help determine the shelf development process. In particular he found that:

- a steep initial slope will result in a narrower shelf

- sediment characteristics play a major role in the type of shelf development

- fetch length is a poor substitute for wave energy.

A lakeshore profile (as shown in Figure 2) will take time to reach an equilibrium with respect to the size and range of sediments, the prevailing wave energy and the pattern of water-level variations. Artificial adjustments to the water-level regime will alter where the wave activity acts on the profile, and will change the profile form and possibly its position as it establishes a new equilibrium. Significantly lowering the water level would remove the upper part of the profile from the zone of wave action, while the nearshore shelf and offshore face would be actively worked. The effective width of the shelf would then be narrowed, concentrating wave energy on a smaller, across-shore section of the profile, and sediment removed from higher on the profile will be lost off the shelf into deeper water.

Higher lake levels will place the zone of wave activity higher on the profile, and if coinciding with high-energy waves, will cause erosion of the foreshore and backshore with deposition in the nearshore as the shelf agrades and adjusts to the new wave base level (Kirk 1988).

Relict or abandoned shorelines may also be a feature of the landscape around lakes. These may include beach ridges and cliffs a long way from and much higher than the present shore, reflecting paleao-lake levels. Studying them can lead to better understanding of the lake's development, including the wave environment that formed the beaches, and patterns of sedimentation and erosion. Examples of lakeshore beach ridges can be seen on the eastern margin of Lake Taupo at Five Mile Beach, as well as eastern areas of Lake Manapouri. An extreme example (and by no means unique) can be found on the Waimakariri River near Mt White, where Holocene beach ridges remain from Glacial Lake Speight, an ice-dammed lake present around 12,000– 14,000 years ago (Gage 1958).

Biological communities and their susceptibility to lake-level change

Biological communities likely to be affected by changing lake levels are the terrestrial vegetation on the lower foreshore, the marginal and wetland vegetation, and lake-edge aquatic flora and fauna. The extent to which the aquatic biota is affected will depend on the depth of turbulence from wave activity; in lakes with large fetches these effects could be expected to extend down to depths up to 5 m below the lowest lake level. The vertical gradient at the lake edge and substrate size are major determinants of the distribution, diversity and community composition of biota around the lake's edges. These communities can be considerably modified by water-level fluctuations. Depending on the community, observed zonations will reflect recent lake-level regimes. Zonation in the large oligotrophic lakes tends to be similar in lakes subject to natural and artificially extended levels as long as fluctuations are in the order of 0 – 3 m (Stark 1993; James et al. 1996; James, Weatherhead et al. 1999; James, Champion et al. 2000). Features of the different biological communities and their sensitivities to lake-level fluctuations are outlined below.

Terrestrial

Lakeshores, being an ecotone (a transitional zone between terrestrial and aquatic habitats) which is subjected to variations in lake levels, are typically stressful environments where many organisms exist at or close to their tolerance limits. Lakes differ greatly in their frequency and range of variation in water levels, and this is reflected in the lakeshore zonation patterns of both plant (Figures 3 and 4) and animal communities. Hence an understanding of these patterns will be relevant to developing an appropriate lake management regime, if the plan is to retain the natural zonation pattern under conditions of artificial management.

Figure 3: **Lakeshore vegetation zones at Brod Bay, on the western shore of Lake Te Anau, revealed when the level is extremely low. The short turf zone adjacent to the lake is replaced by a taller zone dominated by jointed rush (oioi – *Leptocarpus similis*), which in turn is replaced by a shrub zone dominated by manuka (*Leptospermum scoparium*) and then by tall forest, dominated here by mountain beech (*Nothofagus solandri* var. *cliffortioides*) with scattered emergent rimu.**

Source: Reprinted from Mark et al. 2001.
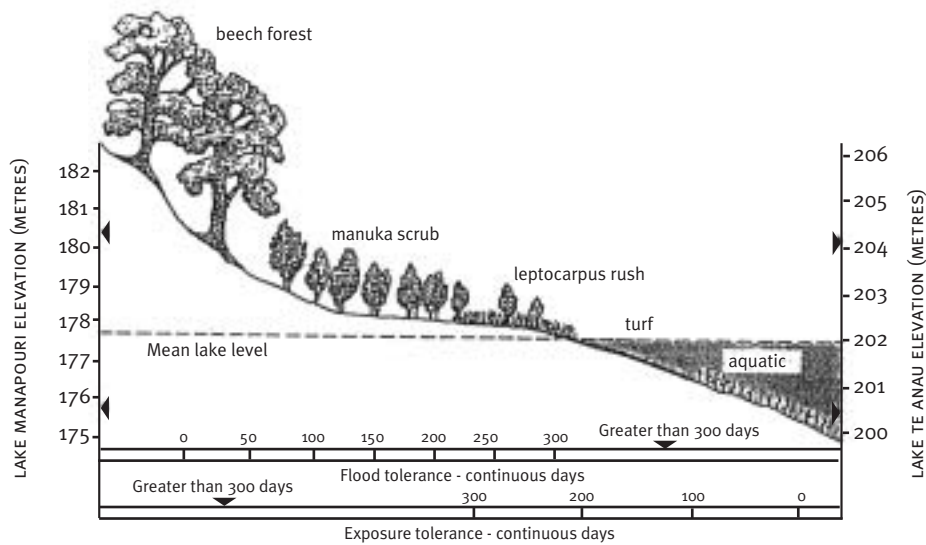
Figure 4: Representation of a typical lakeshore vegetation zonation pattern on relatively sheltered non-rocky sites at Lakes Manapouri and Te Anau. Distribution of each of the five main zones is shown in relation to elevation (Manapouri values left, Te Anau right), and tolerance values to flooding and exposure assumed from analyses of the 37-year record of daily lake levels. Maximum, minimum (arrow) and mean lake levels are indicated for each lake.

Source: Reprinted from Mark et al. 2001.

The woody types of vegetation of forest and/or shrubland that usually occur along lake margins in higher rainfall regions are usually intolerant of prolonged submergence, even of their roots, since aeration is impeded when soil is saturated. In these conditions a series of increasingly stressful chemical reduction products are formed by micro-organisms over a relatively short period of time. As a result, the vertical distribution of lakeshore plants is likely to reflect their differential tolerances to such conditions (see Mark et al. 1977).

Studies of the Fiordland lakes have indicated (Johnson 1972b), and subsequent observations under different management regimes have confirmed (Mark et al. 1977), that mountain beech trees on the lake margins have a maximum tolerance to root inundation of about 50 days. A common lakeshore (and wetland) shrub, manuka (*Leptospermum scoparium*), which dominates a distinct zone below the limits of forest, was assumed from the initial lakeshore zonation studies to have a tolerance limit to root submergence of some 272 days (Johnson 1972b; see Figures 3 and 4), but subsequent studies on the effects of lake-level management indicate its tolerance is substantially greater (Mark et al. 1977), as has also been indicated by autecological studies (Cook et al. 1980). In fact the tolerance limit was found to be more closely related to the period of total inundation – of up to 80 days (Mark et al. 1977). This tolerance explains the fact that, where it is present, manuka occurs at the outer edge of the shrub zone on the lakeshore.

Beyond the shrub zone, the dominant herbaceous plants on the Fiordland lakeshores appeared to be unaffected by prolonged inundation, even exceeding one year (Johnson 1972b), to the extent that they can be considered only marginally terrestrial. These plants, which characterise the rush, sedge and turf communities and, beyond these, the aquatic macrophytes of the upper littoral

zone, while obviously tolerant of prolonged inundation may be vulnerable to desiccation when not submerged. Maximum periods of emergence for species in these zones, based on shoreline zonation studies at Lakes Manapouri and Te Anau, are given in Johnson (1972b; see Figures 3 and 4). This kind of information has been used to derive management guidelines for the levels of these lakes to ensure the retention of their natural zonation patterns (see Mark and Johnson 1985). More details on lakeshore margins, particularly the herbaceous and aquatic macrophyte plant communities, are given below.

Marginal and wetland regions

Wetlands are defined by the presence of plants and animals that are adapted to, or at least tolerant of, wet conditions, ranging from permanent flooding to occasional inundation. Many animals will use these areas when conditions are suitable. Some fish species, for example, will feed in flooded areas, and many bird species feed and nest in these areas.

The distribution and composition of the biota in marginal and wetland regions around lakes is sensitive to several factors, including invasion by exotic species, animal browsing, fire and predation. But the predominant factor is the flooding regime. This regime is determined in turn by physical factors such as topography, soil permeability and proximity to rivers and the lake edge. Lake levels can determine the groundwater levels in adjacent wetlands and therefore play a major role in determining community structure and distribution.

In Lake Manapouri, for example, Johnson (1972a) recorded a plant community dominated by oioi (*Leptocarpus similis*) in areas as low as 0.3 m below where manuka occurred. This was attributed to the relative sensitivities of these species, with oioi able to tolerate about 310 days of submergence but manuka only about 272 days although there is an indication from later studies that they may last longer.[4]

Another example of lake levels determining wetland communities is at Lake Whangape. On exposed shorelines, short marginal turf communities develop after periods of low water levels over summer. The species present include slow-growing amphibious perennial species (such as *Lilaeopsis novae-zelandiae, Elatine gratioloides* and *Glossostigma* spp.) and short-lived annual species (*Centipeda cunninghamii, Alternanthera sessilis* and *Fimbristylis velata*) (Champion et al. 1996). They are often highly diverse. For example, at Lake Whangape 44 indigenous and 91 alien plant species were recorded from an area of 800 m^2 of shoreline over a three-year period (Champion et al. 2001). Similar turf communities occur at Lake Wairarapa and at kettle tarns in the Lake Coleridge area (Johnson 1998), where lake levels drop considerably over the summer months.

Lake levels are sometimes manipulated for flood protection of low-lying farmland. In the case of the Waituna Lagoon in Southland, levels were reduced for this purpose and oioi-dominated vegetation migrated towards the reduced average water level.

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[4] See Johnson 1972b for a comprehensive list.

Drainage of wetlands has become an issue in some regions. The groundwater and surface-water levels are dependent on rainfall, flooding from rivers, evapo-transpiration and the way the water is discharged into water bodies such as lakes. Some wetlands, such as those at the southern end of Taupo, discharge towards a lake and so the lake level can, at least in part, dictate the hydrological regime. At Lake Taupo this effect may extend up to 500 m from the lake edge. This could lead to expansion of wetlands, but vegetation patterns are only likely to be affected if the level changes for a long period – short-term fluctuations within a season are not likely to have a major impact on wetland vegetation.

Indirect effects of changes in lake level on wetland areas may include:

•   greater susceptibility to invasion by exotics such as grey willow

•   increased browsing

•   risk of fire and predation on birds by stoats and weasels.

Grey willow invasion is perhaps one of the greatest threats, particularly in the North Island, and this plant is spreading into all wetland vegetation types where surface water does not exceed 0.6 m depth during spring and early summer, when seedlings establish. This is the situation in the South Taupo wetland (Eser and Rosen 2000; James, Champion et al. 2000), and grey willow now occupies 47.5% of the wetland. In the Whangamarino Swamp (North Waikato), Reeves (1994) reports willow invasion of most areas formerly occupied by herbaceous wetlands.

Aquatic biota

At the water–land interface the plant communities range from terrestrial vegetation (in some cases a wetland margin), to the low-mixed community that may be intermittently submerged, and then to the submerged aquatic plants. Generally the interface between terrestrial and aquatic zones in lakes with changing water levels is referred to as the 'draw-down' or 'varial zone'.

Like the terrestrial and wetland zonation, the structure and distribution of aquatic communities in the shallow zone around lakes are largely determined by physical factors such as slope, substrate type, exposure to wave activity and water-level regimes. Despite this variation, however, some generalisations can be made, and a diagram showing a typical profile is presented in Figure 5. The depth zones at which various communities occur will vary depending on the factors listed above.

DISTANCE FROM SHORE IN METRES

Tall vascular community with *Elodea*, *Myriophyllum Potamogeton* spp. and Characeae

Normal draw down zone no plants

Low mixed community Highly variable

"Drop off" at 7-8m

Tall (<50cm) Characean meadow. (*Chara corallina*, *C. globularis*, *Nitella hyalina*)

Mayfly
Chironomid
Snail
Caddisfly
Oligochaete

Lower boundary at 16m
Chara corallina

DEPTH IN METRES ABOVE SEA LEVEL

Water level

Figure 5: Profile of communities in the littoral zone in Lake Waikaremoana.

Source: Reprinted from Howard-Williams et al. 1989.

The depth range of the zone affected by water-level fluctuations varies considerably. It often has a wave-wash zone of up to 0.5 m in small lakes and sheltered bays of large lakes, and up to 3–4 m on exposed shores in large lakes like Taupo. This zone is characterised by either a sand or coarse sand and gravel substrate with no macrophytes, or a plant community that has been variously referred to as a turf, low-mound or low-mixed community (Howard-Williams et al. 1989). This community is characterised by mostly low-growing native plants such as *Glossostigma* and *Isoetes*, but can include short-growing examples of species such as *Elodea canadensis* as well as characeans. Here we will refer to this community as "low mixed" (see Figure 6). The macroinvertebrate community in this zone is characterised by low abundance but can contain a diverse assemblage, including larvae and nymphs of mayflies and stoneflies, which are usually only found in lotic environments. These species are important food items for fish in lotic systems but their importance in lake systems is usually limited because of their low abundance.

The second zone is below that directly affected by water-level fluctuations. It extends down to depths of up to 10 m and contains a mixed community of plants, but is often dominated by tall-growing vascular species, including the introduced oxygen weeds *Lagarosiphon major* and *Elodea Canadensis* (Figure 7). The replacement of native communities by these invasive exotic species is now widespread in New Zealand. The transfer of introduced species between lakes has been primarily attributed to the spread of propogules attached to fishing equipment and boats. There is no evidence that lake-level fluctuations have contributed to the spread of introduced aquatic weeds.

Figure 6: Low-growing turf community at 1.5m, Lake Wakatipu.

Photo: R Wells

Figure 7:   Mixed plant community at 3 m depth in Lake Waikaremoana, including the oxygen weed *Elodea canadensis*, milfoil, *Myriophyllum triphyllum*, and the pondweed *Potamageton cheesemanii*; and characeans.

Photo: Rohan Wells

Macroinvertebrates are most abundant in this zone, and in most lakes the community is dominated by the snail *Potamopyrgus antipodarum* along with various caddisfly larvae and chironomids. This is also the zone occupied by damselfly and dragonfly nymphs, which can be an important food source for fish. Most of the communities are unlikely to be affected by changing lake levels, except if the levels drop below the normal range and the shallower part of this zone is subject to greater wave activity. Native characeans form an understorey in this zone if there is sufficient light available, and will usually be the dominant component of the vegetation at depths greater than 5–7 m.

The deeper plant zone is usually characterised by a 'characean meadow', which in large oligotrophic North Island lakes like Lake Taupo extends down to 15–16 m (Forsyth and Howard-Williams 1983), and has been recorded to depths of over 30 m in some South Island lakes such as Coleridge and Wakatipu (Schwarz et al. 2000). The bottom limit – at least in South Island lakes – coincides with the depth at which about 2% of surface-incident radiation penetrates (Schwarz et al. 1996). The macroinvertebrate community in the characean meadow is dominated by snails, with increasing numbers and relative importance of chironomids and oligochaete worms with depth. Only during excursions to extreme low levels, well below the normal lake-level range, would these deep plant zones be affected by lake-level fluctuations. In some South Island lakes there is a deep bryophyte community below the characean meadow.

Lake level regimes and potential effects on lake processes

Extensive water-level fluctuations can constrain the size of the niche available to a particular biological community. In the case of macrophytes, the upper depth limit is set by disturbance, water level and wave action. The maximum depth to which characeans extend is generally a function of light availability (Schwarz et al. 1996; 2000). Bottom limits can, however, be influenced by other factors, such as grazing by koura in the case of some North Island lakes (Coffey and Clayton 1988). Where there is sufficient light penetration, vascular plants are thought to be limited by hydrostatic pressure and are generally restricted to water depths less than 10 m, although some species may occur deeper in some lakes (Wells et al. 1994). Any significant change in water level will alter the light climate and hydrostatic pressure experienced by these plants.

The extent of lake-level change can have a dramatic effect on macrophyte distribution, and in extreme cases, where water depth and/or water clarity become limiting to growth, certain species may be eliminated altogether. For example, Norwegian studies have shown that lakes with water-level fluctuations from 3.5 to 6 m resulted in complete eradication of all the main aquatic plant communities (Rörslett 1989). These studies suggested there was a critical threshold range for water-level fluctuations of 7 m per year, although this will be affected by the frequency and duration of the fluctuations.

There have been few comprehensive studies of New Zealand lakes with extensive lake-level fluctuations. Lake Moawhango on the North Island central plateau and Lake Hawea in the South Island have experienced maximum fluctuations of 15 m and 21.9 m respectively. Clayton et al. (1986) did not record any vascular plants in Lake Hawea, but recent surveys following periods of reduced fluctuations (less than 3 m annually) have recorded *Myriophyllum* sp. and *Elodea canadensis* in several locations (Anne-Maree Schwarz, NIWA, personal communication). The only taxa recorded in Lake Moawhango were three native species of characean (Schwarz and Howard-Williams 1993).

The lack of vascular plants in Lakes Moawhango and Hawea was attributed to water-level fluctuations of more than 10 m over the year preceding the surveys. The observations of communities in New Zealand lakes (see the summary in Box 1) are consistent with the observations made in Norwegian lakes, where fluctuations of over 7 m created draw-down zones devoid of vascular plants. The abundance and diversity of macroinvertebrates are determined by the substrate and distribution of macrophytes (James et al. 1998), so the effects of large lake-level fluctuations on macrophytes will be transferred through to macroinvertebrates, and potentially to fish communities.

BOX 1: PLANT COMMUNITIES ASSOCIATED WITH DIFFERENT TOLERANCES TO SUBMERGENCE AND RANGES OF WATER-LEVEL CHANGE IN NEW ZEALAND LAKES

PERIOD OF SUBMERGENCE	PLANT COMMUNITY/TYPE	PROCESS
< 53 days	Mountain beech	Root inundation
<53 days	Kamahi	Root inundation
< 251 days	Pokaka	Root inundation
< 272 days	Manuka	Root inundation
< 80 days	Manuka	Total inundation
< 310 days	Oioi*	Submergence

* More likely to be controlled by desiccation.

WATER LEVEL RANGE	PLANT COMMUNITY
<3 m	Diverse turf communities, tall vascular plants and characean meadows
4–6 m	Few species, mostly characeans
> 7 m	No vascular species; limited to characeans if any present

Long-term changes to lake-level fluctuations, and even some short-term changes (either extreme highs or lows), are likely to lead to changes in habitats. These changes, along with direct physical forcing, will have implications for terrestrial, wetland and aquatic communities. The degree of effect will depend on whether it is a high or a low, the season, and the duration of the extreme event. To get an idea of the significance it is important to compare the managed levels and fluctuations with the natural pattern for a particular lake. A summary of potential effects is given in Table 1.

Table 1: Summary of the potential effects of extreme high and low lake levels in different seasons

REGIME	TERRESTRIAL VEGETATION	WETLANDS	BIRD LIFE	MACROPHYTES
1. Autumn/winter low, spring/summer high.	Freezing in some herbaceous species; mortality due to flooding.	Minor; less chance of invasion by willow; lack of drainage in summer.	Nests inundated.	Freezing in upper macrophyte zone; reduced upper limit in autumn and winter.
2. Autumn/winter high, spring/summer low.	Desiccation in some herbaceous species; mortality due to flooding.	Invasion by exotics in spring/summer.	Increased risk of predators.	Loss of low-mixed communities; replacement by terrestrials.
3. High for most of the year.	Mortality of some species.	Mortality of some spp.; lack of drainage; expansion of wetlands.	Reduced feeding on macrophytes.	Lack of flowering by turf spp.; change to distribution of vascular plants.
4. Low for most of the year.		Expansion of herbacous plants and scrub; increased risk of invasion by willow and other exotics.	Increased predators fragmentation of habitat.	Shift in depth distribution of vascular plants; erosion of offshore face.

REGIME	PERIPHYTON	MACROINVERTEBRATES	FISH
1. Autumn/winter low, spring/summer high.	Little impact; freezing in autumn/winter.	Freezing of some habitats.	Maximises access to spawning streams; only minor impacts.
2. Autumn/winter high, spring/summer low.	Lack of growth; exposure; strandings of filamentous spp.	Desiccation in spring; loss of some habitat for egg laying etc.	Reduced access to streams for some spp; loss of lake spawning; loss of some feeding habitat in shallows.
3. High for most of the year.	Stable community; loss of a few spp.	Minor.	Minor.
4. Low for most of the year.	Strandings of filamentous spp.; proliferations close to nutrient and groundwater inputs.	Loss of some habitat e.g., cobbled areas.	Lack of access to streams; loss of lake spawning habitat: less feeding in cobble habitat; fewer terrestrial foods at hand.

Note: The severity of most of the effects will depend on the duration at different levels and ability to recolonise or reach a new equilibrium.

Effects of high lake levels on physical processes

Erosion, beach and shoreline

High lake levels contribute to shore erosion in two ways. High water levels can force up the water table and saturate the beach sediments, causing finer sediments to become fluidised and move off the shore. This can be a significant contribution to erosion of mudstone shores, such as those found around Lake Waikaremoana, especially when coupled with periods of wetting and drying. However, it is when high lake levels combine with storm waves that more significant erosion can result (see section 1).

Storm events can contribute to high water levels on lakes just as they do on oceanic shores. Pickrill (1978b) found from observations at Slipway Beach, Lake Manapouri, that groundwater tables rose faster than they fell, with maximum rates of change around 30 cm per day (Kirk 1988). Water-table fluctuations were greatest on the upper and lower foreshore (the steeper sections of the beach), and were thought to be controlled by cumulative rainfall and lake-level changes respectively. The higher water tables resulted in accelerated erosion, with maximum changes to the beach sediment volume occurring during periods of rising and falling water levels. Rising water levels produced net erosion (lakeward transport of sediment), while falling levels resulted in accretion (Kirk 1988).

It is important to note that water-table effects will vary greatly from lake to lake and beach to beach. Sediment characteristics will determine the permeability of the beach and may vary from site to site. The relationships found by Pickrill (1978a) will hold for gravels and sands. However, if the beach is composed of glacial till or predominantly fine material, it could be permanently saturated and continually prone to erosion under wave action or slumping if the lake level is lowered rapidly.

The effects of wind and wave set-up, seiching[5] and differences in barometric pressure occur for short periods during storms. Kirk (1988) carried out detailed work on wind and wave set-up on Lake Pukaki. He found that the effects of barometric pressure were minimised because of the small size of alpine lakes, although on bigger lakes such as Lake Taupo the effect would be measurable. Under strong north-westerly winds (winds of 20 to 24 m/s), wind stress set-up was calculated by Kirk to be of the order of 0.25 m while wave set-up at the southern end of Lake Pukaki could be as much as 0.26 m. Combined, the effect can result in water levels being raised by over 0.5 m. Kirk's theoretical calculations were verified by comparing water-level set-up values with the heights of storm berms present on the shores of the lake. These calculations are an important – but often neglected – component to consider when designing shore-protection structures around lakes, such as at the southern end of Lake Hawea (Kirk et al. 2000) and around the north-eastern shore of Lake Taupo (Kirk and Single 2000).

A high lake level combined with strong winds and storm waves can result in erosion of the margins of a lake not usually subject to wave action. In particular, the base of cliffed margins that are landward of beaches may be eroded by direct wave action or destabilised through removal of talus or debris accumulations that protect the base of the cliff from wave attack. This is the case on the southern

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[5] Fluctuations in the water level of a lake caused by sustained wind in one direction or changes in barometric pressure.

margin of Lake Hawea (Kirk et al. 2000), where the erosion rate of the 8 m high cliff is approximately 0.52 m/yr. It is particularly significant where cliffs are formed in glacial till. Kirk et al. (2000) state that the total elevation achieved by the water compared with the elevation of the toe of the cliff where it meets the sloping beach is an important control on cliff erosion. This shows that wave run-up is an important factor to consider, along with the stillwater level and the increment in water level due to wind and wave set-up.

In addition to eroding beach sediments and transporting them lakeward, high water levels can also result in the building of constructive features or berms at the limit of wave run-up. This is more common on coarse-grained or gravel beaches than on sand beaches. As a consequence, the upper beach becomes steeper and the lower part of the beach becomes flatter. If the beach is of a barrier form, the material can raise the height of the barrier, or roll over the top of the barrier creating a backslope to landward. The material is then lost from the active swash zone of the beach and is not available for redistribution across the beach unless the beach as a whole retreats landward. In effect, the beach sediment budget has undergone a loss.

Material transported landward in this way can bury smaller vegetation and form beach ridges among larger vegetation. When the water levels retreat, the berms are abandoned until the next high water level event. Such features are visible on a number of lakeshores. On some lakes, such as Monowai, berms have also been measured migrating landwards across river fans and into the forest at the lake margin some decades after lake raising. At Monowai these features also reflect a positive sediment budget.

The heights of beach berms indicate the combined effects of water level and storm wave run-up, which makes the landscape a structural record of maximum water-level and storm conditions.

Inundation

Inundation can result from lake water levels being higher than the active shoreline of the lake, as can occur during high rainfall events. In effect, the water body submerges the marginal land up to a surrounding contour equal to the water level. Smaller-scale inundation can occur as a result of wave run-up overtopping the beaches. Generally this will result in smaller volumes of water than with high rainfall, but is likely to occur in conjunction with high water levels and strong winds. These conditions may inhibit drainage of the water back to the lake. Erosion of the beaches may also be enhanced. Where the beach forms a barrier with lower land behind it, overtopping water may become ponded, either temporarily or permanently.

Structures – effects of high and low water levels

Shore structures around lakes are built for a variety of purposes, but the two most common are for water sports such as fishing and boating (for example, jetties and boat ramps) and as 'shore protection' (for example, walls and revetments running parallel to the shore, and groynes running normal to the shore). Structures built as 'shore protection' do not protect the shore as such but are built to protect assets such as houses, which may be at risk from erosion or inundation. Where such structures are already in place, it is important that they do actually function as protection, and do not adversely affect the lakeshore environment. Beaches

commonly have a high recreational or aesthetic value, which should not be unnecessarily compromised by the presence of unsightly protection works. Jetties and boat ramps function to give access to the water, but should still follow designs that are sympathetic to lakeshore processes. All structures should be designed for the known water-level variations at their particular site. Significant changes in water levels will have an effect on both types of structure.

Water levels significantly higher than normal may overtop or flood jetties, taking them out of service. If accompanied by storm waves, the structural integrity of jetties, and especially of the deck materials, may be weakened by the impact of waves on the decks or cross-members. High water levels will normally have little effect on boat ramps but may lead to erosion of softer sediments around the top of the ramp. Hard ramps may also act to enhance wave run-up, as swash will not percolate into the surface. Wave run-up heights and inundation levels may therefore be increased in the vicinity of a boat ramp.

Water levels significantly lower than normal may also render jetties inoperable – the jetty may no longer be over the water body, or the water may be too shallow to allow vessels to tie up. Boat ramps may also be unusable if the water level is lakeward of the end of the hard ramp. Where the ramp ends abruptly or into soft sediments, localised holes and erosion around the structure may develop, which could be hazardous. Channels from harbours or marinas may also be unusable by some vessels at extremely low water levels, as has occasionally been the case at Kinloch on Lake Taupo.

The US Army Corps of Engineers, Coastal Engineering Research Centre, produced a guideline for construction and maintenance of shore-protection structures for works built on the Great Lakes. The rules are as follows:

1. Provide adequate protection for the toe of the structure so that it will not be undermined.

2. Secure both ends of the shore protection works against flanking.

3. Check foundation conditions.

4. Use material that is heavy and dense enough that waves will not move individual pieces of the protection.

5. Build revetments high enough that waves cannot overtop it (spray overtopping is all right, but not 'green' water).

6. Make sure that voids between individual pieces of protection are small enough that underlying material is not washed out by waves.

High water levels may test rules 2, 4, 5 and 6. In particular, structures must be high enough to cope with wave run-up from storm waves occurring on top of high water levels (including wind and wave set-up). Therefore the potential storm conditions must be known or calculated and considered in the design of structures.

Low water levels will test rules 1, 2, 3, 4 and 6. The foundation conditions for the structure are especially important, as when levels are at lower than normal they may become undermined and destabilised. This has happened at the southern end of Lake Pukaki (Kirk 1988). Kirk and Single (2000) discuss these rules with particular reference to structures around Lake Taupo.

Destabilisation of marginal habitat – effects of high and low levels

Abnormally high lake levels, when combined with strong onshore winds, can damage lakeshores through wave action, particularly in more vulnerable areas. Undercutting of unconsolidated lakeshore sediments protected with vegetation is not normally a problem on the shorelines of natural lakes managed within their natural range of levels, but might be minimised, as in the case with the management guidelines for the vulnerable Fiordland lakes (Manapouri and Te Anau), by avoiding high levels during the equinoxial periods.

Destabilisation can occur through the 'combing-down' of beach sands if low lake levels are maintained for unnaturally long periods and the gravel is lost over narrow shelves into deep water, as with the Fiordland lakes (see Figure 8). Shorelines can also be destabilised if draw-down rates in excess of the maximum natural rates are used on lakes with shorelines composed of fine glacial till, or comparable material, which drains only slowly. Such puggy 'incompetent' till sediments, which underlie most beaches on the Fiordland lakes, usually gain in strength as they drain. Allowing for this in the development of management guidelines for Lakes Manapouri and Te Anau has avoided a repetition of the localised rotational slumping that occurred at Surprise Bay, Manapouri, in August 1972 (Figure 9). This occurred when the lake's level was artificially lowered rapidly to less than 1 m below its minimum natural level (see Mark et al. 2000).

The loss of entire beaches is possible where their shelves are narrow and overhang deep water, as in the Fiordland lakes, if levels are lowered below the natural minima. This occurred with Lookout Beach, Lake Manapouri, in August 1972 when its level was briefly lowered to only 80 cm below its natural minimum level, but sufficient to allow wave action to collapse the shelf. Having been destabilised the entire beach was soon lost (Figure 10).

Figure 8: Loss of the limited gravel resource from the beach at Stockyard Cove, Lake Manapouri, Fiordland, through 'combing down' by wave action when the level is low. Note the material underlying the gravel consists of soft peaty or silty material, which often contains logs and smaller fragments of sub-fossil wood. (14 April 1975; lake level 175.71 m.)

Photo: A Mark

Figure 9: Localised but serious rotational slumping of the lakeshore at Surprise Bay, Lake Manapouri, Fiordland, apparently caused by the lake being drawn down at a faster than natural rate to a level 80 cm below its natural minimum level for a short period in August 1972. (3 March 1973; lake level 176.39 m.)

Photo: A Mark

Figure 10: Lookout Beach, Lake Manapouri, showing loss of sand associated with collapse of the outer edge of the shelf or offshore face (see Figure 2), apparently when the lake level was lowered 80 cm below its natural minimum level for a short period in August 1972. Loss of sand is indicated by the exposed peat and jetty piles (both covered immediately before the event) and the unweathered section of the rocky shore beyond. (14 April 1973; lake level 175.76 m.)

Photo: A Mark

Effects of low lake levels on physical processes

Erosion and slumping

Low water levels remove the upper part of the beach profile as a result of wave action. At the same time, the nearshore shelf and offshore face of the profile (see Figure 2) are subjected to the energy of breaking waves. Because of the generally narrow, shallow shelf on lakes, low water levels effectively decrease this zone of wave energy dissipation, so the breaking waves have greater energy to do work on a smaller area, and potential sediment entrainment will be greater.

Low water levels also place the wave action near to the upper edge of the offshore face. Steep storm waves coupled with bottom-return currents can transport sediment off this face into deeper water, where the sediment is permanently lost from the beach system. Kirk and Henriques (1986) discuss the effects of this material on macrophyte communities. Altered patterns of lake levels with increased durations at lower levels will result in redevelopment of the offshore face of the beach profile and distribution of eroded sediments onto and down through the macrophyte beds, disrupting these communities.

Lowered lake levels during the early operation of the Manapouri power station resulted in slumping of the turf shoreline at Surprise Bay in August 1972 (Figure 9, *Plate 22.6 from LMH,* Vant 1987). This came about because of the loss of hydraulic support for incompetent materials such as glacial silts, muds and clays. At Surprise Bay this local saturated slumping occurred during an isolated brief excursion 0.8 m below the natural minimum lake level, and resulted in the loss of an entire

beach (see Figure 10 and Pickrill 1976). Other effects of low levels on softer shore materials, such as the mudstone shores on Lake Waikaremoana, include increased erosion of the weathered surface by streamlets and rills of surfacing groundwater.

Draw-down rates/ramping

The effects of draw-down rates (the speed at which the level of a lake is lowered) or ramping (the speed of raising water levels) on lakeshores has been the subject of few studies. Pickrill (1976) identified the effects of a rapid draw-down on Lake Manapouri in 1972. This work is a field example of the theoretical effect. The loss of hydraulic support of fine sedimentary materials resulted in slumping of the shore (see Figure 9). Slower draw-down may allow the soil-water content to equalise as the support of the shore from the water subsides, but there have been no studies to identify actual effects. It is likely that lakeshores will adjust with no adverse effects.

Rapid ramping rates occur naturally where intensive rainfall and catchment flow have a significant effect on lake levels, as occurs in Fiordland and Lake Waikaremoana. Apart from possible inundation, there are no likely adverse effects. Similarly, slow ramping rates occur naturally and lakeshores adjust to these level changes.

Where rapid changes in lake level do occur artificially, human uses are more likely to be affected than are natural systems, so adequate warning and education of lake users is advised.

Sub-aerial processes

Little study has been done on the effects of low water levels on sub-aerial processes on the margins of lakeshores. McGowan (1994), who examined subsequent dust problems at Lake Tekapo due to long periods of low water levels, proposed that high lake levels may recharge deltaic surfaces around the lake with silt. Flood events also leave extensive silt deposits on the broad alluvial channels. The deposits are subjected to deflation by the near-ground airstream when dry, particularly during moderate to strong foehn (nor'west) winds.

Wind-blown dust particles can affect lakeside communities. McGowan found that Tekapo Village can be exposed to dust from the exposed shores of Lake Pukaki (20 to 25 km to the west). He also found that dust storms were a frequent phenomenon during the Pleistocene. Contemporary dust storms are largely confined to the braided river systems, where there is abundant silt-sized material and winds are topographically reinforced. He noted for Lake Tekapo that if the lake levels were not below 703 to 703.5 m amsl (above mean sea level) then areas of the deltaic surfaces may remain moist due to capillary rise of water. When levels are lower, extensive silt deposits on the slopes of the Godley and Cass River deltas will dry resulting in dust storms such as those experienced in the spring of 1989. Similar problems have occurred with Lake Hawea and Hawea Township. It is important, therefore, to minimise the draw-down of lake levels when seasonal wind events that may result in dust storms are likely.

Less is known about the effects of wetting and drying processes on shore platforms formed into hard rock shores. Stephenson and Kirk (2000) examined this phenomenon at Kaikoura on mudstone and limestone surfaces, and noted

that the coincidence of an uncovered surface with periods of sunshine was an important condition for wetting and drying processes to occur in the tidal environment. On lakes, this condition may be more likely to occur as levels may be low for an extended period. The effects of wetting and drying have been observed at Lake Waikaremoana by Kirk (1997), and they are presently part of a PhD study on shore platform development by Anna Taylor (University of Canterbury). Flaking of softer rocks and swelling and cracking of harder rock types has been observed and measured at Lake Waikaremoana. The weathered material is subsequently removed from the rock surface by wave action at higher water levels, or rainfall runoff across the exposed surface at low lake levels.

Effects of different water levels on morphology

Changes in water level can contribute to the marginal geomorphology of lakes apart from changes to beaches. Stream catchments feeding into lakes adjust their channels to the base level provided by the lake. Lowering of levels can induce scouring of the beds of channels and bank undercutting at a distance upstream. Mark and Kirk (1987) report this effect occurring on Lake Manapouri during 1973–74 during construction of the lake control structure. The effect is also evident on Lake Pukaki, and has led to bank stability problems at Whale Stream.

Patterns of deposition of any sediment carried by streams or rivers into the lake may also be controlled by the lake level. However, the primary control will be the amount and type of sediment carried by the water course, and the rate of supply. Sediment delivered to the lakeshore at lower levels may build up as spits or bars (for example, at the Kurutau and Waitahanui Rivers into Lake Taupo). As levels rise, the sediment is redistributed to the beaches. The orientation of the shoreline may also vary at river and stream mouths at different water levels, reflecting the shape of the fan or delta deposit.

At high water levels, streams will be subject to a backwater effect that will penetrate up the stream, much as tidal bores penetrate oceanic river mouths. This may cause flooding of low-lying stream margins.

Large river deltas (or fans) are also present at the head of some glacial lakes, such as Pukaki and Tekapo (the Tasman and Godley Rivers respectively), and on Lake Taupo (the Tongariro River). Because of the low slopes of the lower reaches of the glacially fed rivers, changes in lake water level can inundate large portions of these river fans. Another consequence where there is a large range in the water level is that the effective fetch length for the lake can be significantly different for the low and high water levels. This means that the possible wave heights on the lake can also vary greatly. For example, the main axis of Lake Pukaki increases in length by about 50%, from 20 km at low water levels to about 30 km at higher levels (Kirk 1988). Where the lake levels are less variable, low-lying river deltas can also be subject to inundation during floods.[6]

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[6] Hicks et al. (2000) discuss the delta formation of Lake Taupo in detail.

BOX 2: SUMMARY OF THE EFFECTS OF ALTERED LAKE LEVELS ON PHYSICAL PROCESSES

High water levels can:

- determine where the work of waves is done

- if accompanied by storm waves, result in erosion of the upper foreshore and possibly overtopping of barrier beaches

- transport sediment onshore out of the active beach system

- lead to erosion of the base of cliffed shorelines

- raise the beach water table, making the beach more susceptible to erosion.

Low water levels can:

- cause storm waves to erode material off the nearshore shelf and offshore face

- transport sediment, which may result in damage to macrophyte communities on the nearshore face

- cause wetting and drying of mudstone shore platforms to occur, with enhanced erosion of fine material

- cause incompetent materials to slump due to removal of the hydraulic support of the lake water.

Effects of high lake levels on the lake biota

Birds, wetlands and macrophytes

The impact of high lake levels on bird life is generally indirect and mediated through impacts on macrophyte beds and adjacent reed, rush and sedgelands, which provide feeding grounds and refuge from predators. There are also direct effects, such as high levels impeding access to these areas by species such as black swans, which feed on surface-reaching macrophytes. Most aquatic birds nest on or close to the ground, so rising lake levels during the breeding season could lower reproductive success as nests are flooded. This is likely to be most dramatic if lake levels rise quickly (over 10 cm per day, Paul Sagar, personal communication) to high lake levels.

The major effects of high lake levels on wetlands are likely to be through alteration of hydrological regimes and changing the extent of various plant habitats, rather than total elimination of species. Higher lake levels can increase the area of rush and sedgeland at the expense of shrubs such as *Coprosma propinqua* and manuka. Grey willow could also occupy greater areas, replacing native shrub communities, as it is tolerant of much higher water tables (Eser 1998).

Another potential impact of high levels could be increased shoreline erosion of unconsolidated material higher up on the shoreline. While this would generally leave much of the littoral zone intact, there is evidence that increased downward movement of sediment through macrophyte beds can occur, as at Lake Ohau (Wells and Clayton 1989). Remobilisation of uncompacted fine sediment could

also increase turbidity around shorelines, altering light penetration and (potentially) benthic littoral primary production, but this effect is likely to be relatively short term.

Prolonged high lake levels can detrimentally alter the light environment for deep communities and hydrostatic pressure experienced by vascular plants. However, characean communities have been shown to be resilient to periods of weeks to months of reduced light levels (Schwarz and Hawes 1997).

Terrestrial vegetation

The effects of inundation on terrestrial vegetation may be through partial or total submergence of the plants, or through waterlogging of the soil. The latter is probably more common since waterlogged soils develop an oxygen deficiency within a few hours of flooding. This may act directly on the plants, but is more likely to be an indirect effect of the production of toxic reduction compounds by anaerobic soil micro-organisms. There is an associated reduction in the redox potential of the soil (usually accompanied by an increase in pH), which can be measured with a platinum probe immersed in the soil and an eH meter. Many terrestrial plant species are killed by even brief waterlogging, while others have a variety of responses – physiological and/or morphological – that enable them to survive flooding of their root systems for varying periods (see Crawley 1997). For example, partially submerged manuka plants develop specialised ventilating tissue (or aerenchyma) in the bark below the waterline. Measurements of redox potentials in the rooting zone of soil of potted manuka plants submerged for six months in stagnant water gave a value of -432 ± 5 millivolts (corrected to pH 7); this corresponds to the reduction of sulphate to sulphide (Ponnamperuma 1965), which is highly toxic to most plants (see Cook et al. 1980).

After flooding, the time needed for saturated soil to drain will vary with soil texture, but if drainage is incomplete before flooding recurs the deleterious effects of inundation could be accentuated.

Effects of low lake levels on wetlands and birds

The effects of low lake levels on birdlife depend largely on the indirect impacts mediated through effects on macrophyte beds and inshore reed, rush and sedgelands. Prolonged low levels can also result in fragmentation of wetlands, resulting in a major impact on the number of birds supported. Other factors associated with low levels that could affect the bird populations include increased invasion of wetland vegetation by grey willow and increased risk of fires. Prolonged extreme low levels during the breeding season (mostly August to November) will increase access to these areas by humans, wandering stock, and predators such as cats and mustelids. The resulting disturbance has the potential to affect breeding success.

Many bird species such as the New Zealand dabchick, New Zealand scaup and shags require good vision for feeding underwater around the shallow margins of lakes. If low water levels lead to increased resuspension of sediments and increased turbidity, then feeding success and access to some aquatic prey could be impaired.

Effects of low levels on aquatic communities

Aquatic plant communities most at risk from low lake levels are the low-mixed communities. Low lake levels will have both direct and indirect effects. Direct effects include desiccation and freezing of habitats, and physical disturbance through wave activity and sediment mobilisation and movement. Indirect effects include alteration to habitats that are important as refuges from predators or for feeding by invertebrate and fish species. The significance of these impacts will depend largely on the extent, duration and timing of low-level events and the ability of these communities to recover.

Freezing

If low levels occur during winter months, then freezing ground temperatures will impact on shallow communities even over one to two days. Some species are more susceptible than others. Macroinvertebrate groups like chironomids and oligochaete worms are able to migrate deep into the substrate, but gastropod molluscs and mayfly nymphs often suffer high mortalities. Viner et al. (1989) studied the impact of overnight freezing in Lake Aratiatia and found even short exposures caused mechanical disruption of up to 30% of the *Lagarosiphon* beds, while many shallow plants like *Isoetes* were killed. Most macroinvertebrates survived, with the exception of the introduced snail *Planorbarius corneus*, of which 23% of the population was lost. As long as draw-down rates are not too fast, most fish species will migrate to deeper waters as the level recedes.

An indirect effect of freezing is the potential increase in organic detritus from decaying macrophytes, which could stimulate increases in detritivorous invertebrates such as chironomids and oligochaetes. Most macroinvertebrates, however, inhabit the deeper macrophyte beds so are unlikely to be affected.

Desiccation/drying out

Prolonged or frequent low levels that result in drying out of the shallow habitats during low lake levels can cause qualitative changes, particularly in the macrophyte community. Some of the plant taxa present can produce terrestrial forms and/or have deep buried rhizomes and roots (for example, *Myriophyllum* spp), which allow them to survive relatively long periods of exposure. *Lilaeopsis, Glossostigma* and *Isoetes* will tolerate periodic short-term emergence (Coffey and Clayton 1988), and many native shallow-water species of these will only produce flowers and seeds when emerged.

Exposure to wave activity

While low-growing mixed communities have a degree of resilience and can withstand relatively strong wave activity, the taller mixed vascular plants in the next zone down are generally more susceptible to damage. The upper limit for this zone is set by the degree of exposure to wave activity. A clear positive relationship has been established between the upper depth limit for tall vascular macrophytes and degree of exposure (James, Champion et al. 2000). Maximum biomass and plant heights in lakes are generally found in sheltered bays. Howard-Williams and Davies (1988) developed a multiple regression relationship for height and biomass of *Lagarosiphon* in Lake Taupo, and showed that 60% of the variance could be explained by slope, fine sediment content and effective fetch. The slope of the regression for exposure index versus upper depth limit in the relationship for low-growing turf species was much less pronounced, suggesting

that – as expected – tall vascular plants are more susceptible than low-growing taxa (James, Champion et al. 2000).

Physical damage can also occur to the shallow macroinvertebrate community if low levels expose these habitats to strong wave activity. Some species like mayflies, which live under cobbles-rocks, may be resilient, but others such as the snail *Potamopyrgus* can be physically transported below the level of strong turbulence. There is some evidence for this, as peak abundance of *Potamopyrgus* is often just below the region affected by wave activity. When lake levels dropped significantly in Lake Coleridge, for example, so did the depth at which snail distribution peaked (James et al. 1996). The mobility of fish generally means they can avoid regions of high turbulence.

Unsightly strandings of filamentous algae occur regularly in some bays of Lake Taupo, and concern has been expressed that this could be exacerbated by low lake levels. Wind and wave activity simulations and records of strandings of *Enteromorpha*, however, do not indicate a strong association between the timing and magnitude of strandings and water level, or the depth to which wave activity penetrates.

Macrophytes

Although low water levels can change the light available at depth for plant growth, significant changes are only likely to occur after prolonged periods of low water level. For example, Howard-Williams et al. (1989) found the lower limit for growth of characeans in Waikaremoana was stable over five years in spite of large (3 m) short-term (two to three months) variations in water level. There were, however, changes to shallow communities. The vascular plant *Elodea canadensis* migrated downwards by 1.5 m as a result of low water levels, and remained at this depth for the following three years despite the rise in lake level. Short and flattened specimens of *Potamogeton cheesemanii* and *Myriophyllum triphyllum* survived on the damp mud (Figure 11) among terrestrial weeds (thistles and docks). Recovery of these species was rapid when the lake rose – within three months, tall dense beds of *Myriophyllum* were observed (Figure 12). Regrowth of macrophytes following low lake levels will either be from vegetative invasion of existing plants or from seed germination. Thus for some species, maintenance of seed banks is critical for recolonisation of areas when lake levels rise again.

Figure 11: **Shallow habitat consisting of damp mud exposed during extreme low lake level in Lake Waikaremoana.**

Photo: C Howard-Williams
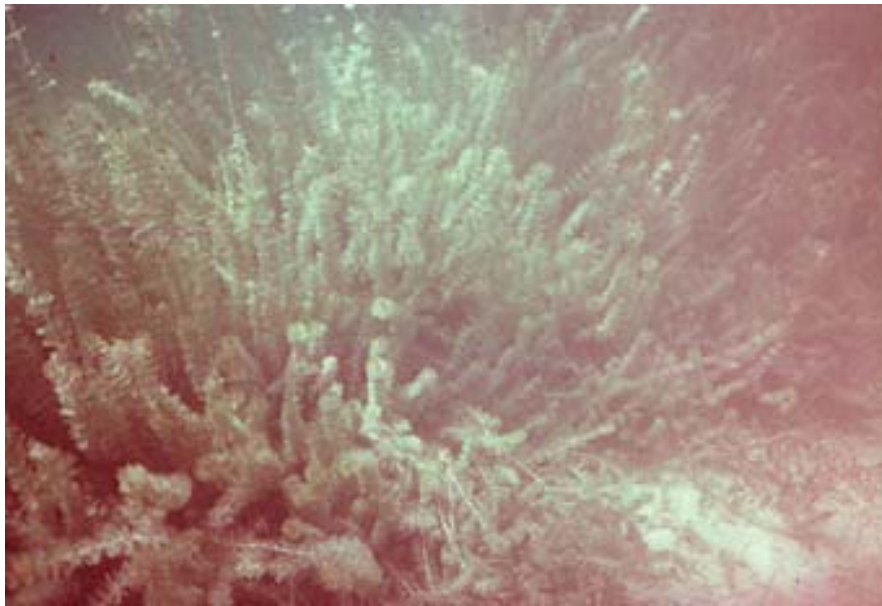
Figure 12: ***Myriophyllum*, which had been exposed in Lake Waikaremoana in 1982/83 and recovered during reflooding in November 1983.**

Photo: C. Howard-Williams

Periphyton

Periphyton communities are generally very resistant and resilient to changes in lake level, particularly the taxa found in the wave-wash zone. The periphyton community most likely to be affected by low lake levels are the epiphytic forms attached to plants. Most periphyton taxa tend to reproduce year round and

propagate *in-situ* by binary fission, with some producing motile spore stages for recolonisation. Hawes and Smith (1993) showed that, following winter lows in Lake Taupo, biomass and species composition had recovered within less than two months after the water level rose. Similarly, a later survey in 1998 (James, Champion et al. 2000) showed that high periphyton biomass and a diverse community structure were present on cliff faces at levels that had been exposed to the air for six months only 2.5 months previously. A residual population of periphytic diatoms and cyanobacteria, characteristic of the wave-wash zone, has been shown to survive emergence for at least six months in Lake Taupo, and some cyanobacteria taxa are known to tolerate desiccation for several years (Hawes et al. 1992).

Macroinvertebrates

Low lake levels can have both direct and indirect effects on macroinvertebrate communities. Direct effects include stranding of taxa that cannot migrate or withstand periods of desiccation. Indirect effects are generally through loss of habitats, particularly those with cobbles and macrophytes, which provide an extensive three-dimensional substrate for periphytic algae (the major food source for macroinvertebrates), egg-laying and tube building, and also provide a refuge from predation.

The areas most likely to be affected by low lake levels are the wave-wash and draw-down zones occupied by turf and/or cobble substrate. This region is analogous to river habitats with well-oxygenated, heterogeneous substrates, and although macroinvertebrates are generally present in low numbers the community can be very diverse (James et al. 1998). This is the only region where nymphs and larvae of mayfly and some caddisfly and stonefly taxa are found. These taxa, along with dragonfly and damselfly nymphs, which are often found in the shallow macrophyte turf habitats, are of high ecological value because of their importance in the diet of adult native fish (for example, bullies) and juvenile and adult salmonids.

Fortunately, most macroinvertebrate species can recolonise when the lake level rises and egg-laying takes place. This generally occurs in spring, but some taxa (for example, chironomids) may have several generations a year.

Only a limited number of studies have been carried out in New Zealand on the effects of duration of low levels on recovery rates for macroinvertebrates. Generally the distribution and community composition reflect the lake-level history at a scale of weeks to months. Stark (1990) found macroinvertebrate densities were reduced after exposure for only 10–12 days in Lake Benmore, but whether animals died or migrated down into the hyporeic zone is not known. Chironomids can survive for up to three months by burrowing up to 20 cm into the substrate (Kaster and Jacobi 1978). A recent survey of Lake Taupo found an abundant and diverse fauna at depths of 0.5 m among cobbles that had been exposed for up to six months only 2.5 months previously (James, Champion et al. 2000). In the Lake Taupo case, however, strong wave activity and precipitation could have helped keep the habitat damp.

Recovery of macroinvertebrates following low lake levels is likely to take several months rather than weeks (see the summary in Box 3), and will depend on the timing and duration of low levels. Surveys of Lake Coleridge repeated after an

extreme low event (James et al. 1996) indicated that total abundance and species diversity can probably return to similar levels within three months over the spring/summer period. Recovery of some macroinvertebrate taxa is likely to be on a time scale of weeks, while others will take several months. Chironomids and oligochaete worms, for example, appeared within weeks of the substrate being covered by rising lake levels, but some caddisfly larvae and the snail *Potamopyrgus antipodarum* took up to three months to start recolonising.

Initial changes will in part be attributable to low lake levels causing a shift from stony to muddy shorelines. Recovery of these habitats under these conditions will depend on physical processes restoring substrate conditions. If the deeper, tall-growing macrophyte beds are affected, however, a return to previous macroinvertebrate community composition could take at least two to three years. Some species may be replaced, although total diversity (number of different species) may be restored. Some of the invertebrate species most sensitive to low levels are the crustaceans (for example, the amphipod *Gammarus* and isopod *Asellus*), but crustacean macroinvertebrates are rarely found in New Zealand lakes.

Fish communities

The mobility of fish means that low lake levels are likely to have only minimal direct affects in most cases. Potential impacts include restricting access to spawning grounds in streams, and decreases in spawning habitat around the lake edge. The indirect effects will include loss of cobbled habitat occupied by 'high value' prey items such as mayfly nymphs and caddisfly larvae. However, a recent study of trout diet in Lake Taupo (James, Champion et al. 2000) and food-web studies in Lake Coleridge (James, Hawes et al. 2000) suggested some fish (juvenile trout and koaro) in the shallow regions of some lakes may rely more on terrestrial material dropping onto the water surface than on aquatic invertebrates.

Changes in water level can change the geomorphological characteristics of stream and river mouths. If these changes result in increased water velocities, then access by some fish species may be impaired. Many native species such as koaro (*Galaxias brevipinnis*) are good climbers, but others such as smelt (*Retropinna retropinna*) would be limited to streams with velocities under 0.27 m/s. Timing of low lake levels could be critical in some cases, with low levels in spring potentially having the greatest impact.

Spawning success for fish that lay their eggs in the shallow zone of lakes will be affected if large areas of habitat are lost through low levels occurring at critical times of the year. Smelt, for example, are thought to spawn in spring on clean sand in the likes of Lake Taupo and the Rotorua lakes at water depths of 0.5–3 m (Stephens 1984). These eggs only take 10–12 days to hatch, however, so unless ramping rates are rapid they should not be subject to desiccation. Bullies will spawn on any hard substrate, and although shallow cobble areas may not be available at low levels, there are likely to be suitable substrates at greater depth.

BOX 3: SUMMARY OF RESILIENCE AND RECOVERY RATES FOR AQUATIC BIOTA

Macrophytes
- Macrophytes that are usually submerged can be significantly affected after exposure to freezing for a few days and to drying out for several days.

- A few native taxa can survive emergence for several months.

- Many species in the low-mixed communities can survive several weeks of emergence and recover quickly.

Periphyton
- Epiphytic forms can be lost if macrophytes are significantly affected.

- Many taxa can recover within a few months.

- Some diatoms and cyanobacteria can survive exposure for several months.

Macroinvertebrates
- Shallow communities of mayflies, stoneflies and caddisflies can recover rapidly in spring and autumn.

- Early colonisers (less than three months after inundation) are chironomids and oligochaete worms.

- Snails, and mayfly and dragonfly nymphs may take several months to recover, depending on the timing of lows.

- If macrophyte habitat is lost then recovery of macroinvertebrates associated with the macrophytes could take at least two to three years.

Ramping rates

Ramping rates can significantly affect the ability of lake biota to withstand changing lake levels. There have been no studies in New Zealand, but overseas research suggests that mobile littoral macroinvertebrates can keep pace with water level rises of 0.63 cm/hr but will get left behind at rates of 1.25 cm/hr (Winter 1964).

Rates of lake-level change are likely to be well below this threshold, except in small hydro-lakes like Roxburgh (Winter 1964) and lakes on the Waikato River.

Reversed periodicity

Large New Zealand lakes generally have natural cycles of lake levels, increasing through winter and early spring, then dropping during summer and autumn. In glacial and snow-fed lakes the winter/spring increase may be delayed, depending on climatic conditions.

Concerns have been raised that this natural periodicity has been altered in some lakes used for hydro-electric storage. In Lake Waikaremoana, for example, Mylechreest (1978) suggested that a seasonal periodicity of high summer levels and low winter levels had replaced and reversed the natural cycle of higher levels in winter and lower levels in summer (reversed periodicity). Recent records,

however, suggest that seasonal periodicity is now similar to the natural cycles in Lake Waikaremoana.

When analysing periodicity it is important to consider longer-term climatic conditions as well as short-term weather patterns. Lake Waikaremoana is a good example where there is considerable yearly variation. In 1996 heavy rains in January increased the lake level by nearly 2 m in the space of a few weeks, and levels remained high for several months, whereas in January 1998 levels continued to drop through summer to very low levels in autumn.

Lowland lakes, particularly coastal lakes, are subject to filling from catchment runoff, and water levels reflect regional rainfall patterns. However, the levels of some coastal lakes (such as Lakes Ellesmere and Wainono) are artificially maintained to prevent flooding of surrounding (mainly) agricultural land. This activity predates European occupation, and little is known about its effects compared to allowing the lakes to flood until natural breaching of the impounding barriers occurs.

The sort of problems reverse seasonal periodicity could cause include reduced habitat for egg-laying by invertebrates, and fewer feeding areas for juvenile fish. Reduced lake levels in spring will decrease the extent of cobble habitat where many insect larvae lay their eggs, and reduce periphyton growth, which would in turn affect many macroinvertebrate taxa that rely on periphyton algae as their major food source. This could also affect areas available for fish feeding and spawning if they rely on shallow cobbled or sandy areas. Some invertebrate taxa, such as dragonfly nymphs, are thought to migrate to shallow water in winter in preparation for emergence in spring. Lake levels at this time could affect their susceptibility to fish predation, particularly if large open sandy areas are exposed.

Effects of low lake levels on groundwater

Groundwater can contribute a significant amount of hydrological and nutrient loading to lakes. Hydrological inputs to Lake Taupo have been estimated at 1% of total land drainage (although recent estimates are higher, Bill Vant, personal communication). The most likely environmental impact of low lake levels is alteration of hydrological processes. Drainage of wetlands is a concern in many areas and, if levels are high, discharge close to the lake is impeded and wetlands can expand over farmland.

Eser and Rosen (2000) have suggested that levels of Lake Taupo are now up to 20 cm higher in summer than pre-control, and this has increased water levels in the Stump Bay wetland area, which has expanded by up to 500 m inland. Despite these high levels there is some debate over whether this is due to the management of Lake Taupo, or other factors such as tectonic movement causing subsidence in that area, or even changes in flows in the Tongariro River.

Low lake levels have the potential to increase drainage though a greater discharge of water. Localised nuisance algal growths are observed where groundwater from urban areas enters shallow, sheltered bays in lakes, and prolonged low levels could exacerbate this problem. In some situations, groundwater inputs may appear as seeps at low lake levels and nuisance growths of periphyton and bacterial slimes may develop around these seeps. This is likely to be a more significant problem

where septic tank effluent contaminates groundwater, which could in turn enhance algal and slime growths.

Lake-level change and nutrient cycling

There have been no specific studies of the effect of changing lake levels on the nutrient cycling in the nearshore area, but there is the potential for nutrients buried in the sediments and soils to be released, causing enrichment of both periphytic and water-column algae. An example is Lake Okataina, which has no surface stream draining it and thus undergoes natural lake-level change. As the lake level drops, soluble nutrients could be released from the sediments and some of the resuspended particulate material would be decomposed. Similarly, nutrients would be released into the water when the lake level rises and formerly dry sediment is exposed to wave action. However, if lake-level change is frequent, these sediments may be rinsed out with relatively little nutrient release.

Another example is Lake Rerewhakaaitu, which can show large changes in nutrient concentrations. Previously, it was thought that the increases in nutrient levels were due to increased drainage from land, but it may also be associated with water-level change (John Gibbon-Davies, EBOP, personal communication). Close analysis of changes in nutrient concentrations monitored in lakes that undergo lake-level changes could help explain the occurrences of some of these nutrient and phytoplankton increases.

| **Management**

Resource Management Act

In 1987 the Government determined that all resource consents issued in the form of special empowering legislation for government-owned power stations would be re-issued as normal public consents by the relevant regional government under the proposed Resource Management Act (which was promulgated in 1991). Applications were to be lodged before the end of 2001. The Resource Management Act 1991 (RMA) was the first legislation in New Zealand to adopt an integrated and holistic approach to the use and management of its natural and physical resources. It replaced more than 50 separate pieces of legislation with one act, which has a single overall purpose – promotion of the sustainable management of New Zealand's natural and physical resources – and it followed a major review of these laws carried out by the Ministry for the Environment in the late 1980s.

Any new assessment of the effects of lake-level management needs to take into account conditions set out in the RMA, which was enacted after the *Lake Managers' Handbook* was written in 1987.

Section 5 of the RMA sets out the purpose of the Act, which is "the sustainable management of natural and physical resources". "Sustainable management" is defined as:

> *managing the use, development and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic and cultural well-being and for their health and safety while*
>
> *a. sustaining the potential of natural and physical resources to meet the reasonably foreseeable needs of future generations; and*
>
> *b. safeguarding the life-supporting capacity of air, water, soil and ecosystems; and*
>
> *c. avoiding, remedying or mitigating any adverse effects of activities.*

Further guidance and principles that could relate to lake-level management are provided in Sections 6–8 of the RMA, and include:

- Section 6(a): the preservation of the natural character of the coastal environment (including the coastal marine area), wetlands, and lakes and rivers and their margins, and the protection of them from inappropriate subdivision, use and development

- Section 6(b): the protection of outstanding natural features and landscapes from inappropriate subdivision, use and development

- Section 6(c): the protection of areas of significant indigenous vegetation and significant habitat of indigenous fauna

- Section 6(d): the maintenance and enhancement of public access to and along the coastal marine area, lakes and rivers

- Section 7(d): persons exercising statutory requirements under the RMA must have regard to the intrinsic values of ecosystems. Intrinsic values as defined in the Act means:

  - *those aspects of ecosystems and their constituent parts which have value in their own right, including:*

    - *their biological and genetic diversity; and*

    - *the essential characteristics that determine an ecosystem's integrity, form, functioning and resilience.*

These definitions form the basis for the checklist provided in Section 4 as a guide to what regional councils and managers need to have regard to if lake-level fluctuations are likely to be an issue. (The checklist is not exhaustive and clearly needs to be modified depending on the features of the lake.)

Gazetted guidelines

The resource consents for the Manapouri power station incorporate the formally gazetted *Operating Guidelines for Levels of Lakes Manapouri and Te Anau* as well as discharges from both Lakes Manapouri and Te Anau. The lake management guidelines include the concept of 'best endeavours' (see details below). The management company operating the power station is required to "use its best endeavours" to comply with the details specified for both the high and low operating ranges of each lake. This contrasts with the "gate opening and closing procedures" for some lakes, where the parties "agreed upon and adopted" relevant procedures to provide, among other things, protection for the macrophyte beds along the lakeshores, for the welfare of fish feeding beds and also of their habitat and spawning beds in the associated rivers, particularly the upper Waiau.

Ramping rates for the upper and lower Waiau River, controlled by gate opening and closing procedures for both the Te Anau and Manapouri lake control structures, are now designed to simulate natural flows more closely. The resource consents, issued in 1996 under the RMA, require a minimum flow through the Manapouri control gates of 16 cumecs from November to March, 14 cumecs in April and October, and 12 cumecs from May to September. The upper Waiau River has a minimum flow of 115 cumecs, except if lake inflows are low, in which case it may be reduced, with appropriate consultation, to between 115 and 80 cumecs. Flows less than 80 cumecs must be authorised by the local authority.

There is also an informal agreement, negotiated with Fish and Game NZ Southland region staff, that, if possible, during winter and early spring (May–September) flows in the Upper Waiau River will be managed to encourage brown and rainbow trout to spawn in areas where redds are unlikely to be dewatered.

'Best endeavours'

'Best endeavours' in the Manapouri case, as opposed to 'inviolate rules', was generally considered by the politicians and stakeholders to be a more appropriate constraint for lake-level management, given the capricious nature of the Fiordland climate. Financial penalties were considered and rejected by the Guardians in favour of best endeavours, which require every breach of the guidelines to be fully reported and explained in writing, without delay, to the two relevant Ministers – Electricity (now Energy) and Environment (now

Conservation) – as well as to the Guardians, who were also to be consulted before any breach. (The Guardians were members of the concerned public with relevant expertise appointed by the Government to advise on lake management.) This procedure appears to have been generally satisfactory, according to the Guardians' initial chairperson (Alan Mark). The concept of best endeavours, as applied to the Fiordland lakes, may be appropriate in comparable situations elsewhere.

Approaches to the Resource Management Act

Procedures used for the various power schemes have changed over time. With the Whanganui–Whakapapa–Tongariro River flows associated with the Tongariro power development application in 1988, the managing company, Electricity Corporation of New Zealand (ECNZ), adopted a single-purpose approach in an attempt to retain the maximum water resource, virtually without compromise (Chapple 1987). Initially heard by a combined (Central Districts) catchment boards committee, then unsuccessfully appealed to the Planning Tribunal, and finally to the High Court (again unsuccessfully), this case is generally considered to be probably the lengthiest and most costly legal procedure in the country's history. It also had implications for the company's image and public relations.

A radically different approach, a working party of 10 affected stakeholders, was adopted by ECNZ in the early to mid-1990s for the reissuing of a water right for the upper Waitaki Power Scheme, the country's largest, by the Canterbury Regional Council. Here significant compensatory funding was offered to the Department of Conservation in the form of a river recovery programme aimed particularly at habitat restoration and creation, as well as captive rearing of the locally endemic and highly threatened black stilt (Rawlings and Close 1993). The outcome was considered to have been generally successful, particularly in relation to the conservation of the black stilt, but there was some initial controversy among the local community about aspects of the programme, notably the removal of willows and Russell lupins from the beds and margins of rivers.

A third consent renewal exercise for ECNZ was that for the Manapouri – Te Anau hydro-electric power scheme, to be issued by the Southland Regional Council, in substitution for the earlier empowering legislation (Manapouri – Te Anau Development Act 1963). Here all interested parties were invited to participate in a working party, managed by the Council and funded by the applicant company. Initiated in 1990, the Waiau working party involved representatives of 17 stakeholder organisations. They identified many issues of concern, each of which was the subject of research and a report, commissioned by the working party and funded by ECNZ. Over a period of six years, numerous one and (occasionally) two-day meetings, field trips and 'task groups' produced some 31 reports. The formally gazetted guidelines for lake management (first issued in 1993 under the Manapouri – Te Anau Development Act), together with the provisions for lakeshore monitoring, developed by the Guardians, were incorporated into the application for resource consents.

Given the depth of concern and animosity which this hydro-electric development had generated nationwide over roughly 13 years, it was perhaps surprising – but clearly a reflection of the working party process, the personalities involved, the negotiated compromises and, particularly, the approach and methods adopted by the applicant – that no formal objections were raised when the application was processed by the Council. The consents were issued in 1996 for a period of 35

years. The consents also formalised an ongoing role for the working party, which continues to function in an oversight role. The role of the Guardians has also been recognised, and they have been retained in their formal role as contained in the Conservation Law Reform Act 1980.

A similar approach was taken by ECNZ for consent applications for Lake Coleridge and Lake Waikaremoana. In both cases, working parties involving a range of interested parties were set up and reports prepared to address the issues raised. There were still objections raised at the council hearings, but compromises were made and consents issued with a number of conditions – although there was no provision for ongoing involvement by the working parties.

Contact Energy, a private company established in the late 1990s from the Clutha Valley segment of ECNZ, has recently applied for resource consents associated with the Clutha Hydro Scheme, to be issued by the Otago Regional Council. Contact's approach to this exercise has been to invite stakeholders to notify their interest and then deal with each individually, on a one-off basis; which is to say, the working party approach has not been adopted. This is despite many as yet unresolved issues having serious and widespread community concern (Contact Energy 2001). Another notable feature of Contact Energy's approach to the renewal of its resource consents is its definition of 'the existing environment'. Its *Summary Consultation Document* (Contact Energy 2001), states (p.5):

> *On the basis of relevant case law, Contact Energy considers that the baseline for the assessment of environmental effects should be the state of the environment that currently exists.*

This contrasts with the approach used by ECNZ in its AEE for the Manapouri power scheme (August 1996), which states (p. iii):

> *The initial task of this assessment has been to identify and document the environmental effects which electricity generation at Manapouri Power Station has had on the water resources of the Waiau catchment.*

Management guidelines

Guidelines for managing lake levels will very much depend on what a given lake is being managed for. A lake managed for flood protection, for example, is likely to have a very different lake-level regime – in terms of extent and seasonal periodicity – to one managed for hydro-electric or irrigation storage.

Sustainable management will also depend on the values assigned to these water resources. Values that need to be considered include:
- ecological
- recreational and tourism
- landscape and visual
- social and community
- cultural and spiritual.

Here we deal with only the first three values, and then discuss special cases (coastal lakes and peat lakes).

Clearly some values may be mutually exclusive. For example, maintaining a diverse and productive aquatic plant community may require a narrow range of lake-level fluctuation, but for recreational boating or fishing a shoreward zone of bare substrate may be preferred. In this case it would be a matter of prioritising, or coming to a compromise, depending on the values of the community and users of the resource. Generally speaking, when there is conflict each value and its components will need to be assigned a significance level, and then prioritised.

Values for a lake must be clearly defined at the outset. All stakeholders should be involved, and objectives set to preserve or perhaps even enhance those values. This requires wide consultation in order to set the level of protection in the case of ecological values, while still permitting sustainable use of the resource. In this section we look at some of the management issues, and some options that should be considered.

A key part of any planning for lake-level management is the incorporation of public expectations and perceptions. As discussed earlier, lakes are dynamic systems that undergo natural fluctuations, depending particularly on rainfall. Ideally the managed regime should closely mirror the lake's natural levels in terms of extent, duration and (sometimes) seasonality. Many lakes used for hydro-electric storage are now managed over a greater range than would occur naturally. Examples of narrower ranges, however, are also common, and include Lake Waikaremoana, which now has a mean annual range of 2.56 m, slightly lower than the natural range (James, Weatherhead et al. 1999), and Lake Taupo, which has a natural range of 1.88 m but a managed range of 1.54 m.

In some cases excursions outside the managed range could occur naturally, as with Lakes Manapouri and Te Anau, and it is essential that the full natural range is incorporated into planning documents, particularly those relating to building structures, ramps and land development. These aspects will be discussed later in this section.

BOX 4: CHECKLIST FOR ASSESSMENT OF EFFECTS

1. **Effects on lake levels**

    Lake level: Define natural extent, duration at different levels, ramping rate, periodicity for the lake.

    Extent: What is the range proposed?

                  What is the natural range, and how does the proposed range vary from this?

    Duration: What is the proposed period at high and low levels compared with the natural regime?

    Ramping rate: How quickly will the lake level rise or fall?

    Periodicity: Does the proposed regime have a different seasonal periodicity to that which would happen naturally?

                  Are the changes to the natural periodicity on a daily, weekly, monthly or seasonal (winter/summer) basis?

2. **Effects on physical processes**

    Identify the processes:
    *   wave environment
    *   sediment character
    *   sediment budget
    *   beach morphology
    *   human modifications.

    Set a baseline against which to assess change. Future assessment relies on relocatable measurements of the shoreline and beaches, preferably using photography and field measurements/surveys.

    Monitor changes to the shoreline and beaches, assess and interpret these changes. Interpretation should be carried out by persons with relevant expertise.

3. **Effects on biological processes**

    This assessment requires a good descriptive knowledge of the natural biota as a pre-requisite for all assessments. The assessment should include:
    *   a description of the main features and sensitivities of the plant and animal communities
    *   knowledge of any rare or endangered species or communities present
    *   the extent to which range, duration, ramping rate or periodicity from 1 above are outside the tolerance range that will support important species or communities.

    The assessment should address all components of the ecosystem potentially impacted by changing lake levels, including:
    *   terrestrial vegetation
    *   marginal vegetation and habitats

- birdlife – feeding and nesting habitats
- aquatic plants:

  periphytic algae

  macrophytes – turf or low mixed
  – vascular
  – macroalgae
  – bryophytes

- aquatic animals:

  macroinvertebrates

  fish – native and introduced
  – feeding habitats
  – spawning habitats
  – access to spawning and feeding grounds.

If effects are identified they should be assessed, and there may need to be options for remediation or mitigation.

Summary

- How do the natural regimes compare with the managed regimes?

- Is there likely to be an effect on the physical processes or biota?

- Are the effects minor, significant or major?

- Are there ways to remedy any adverse effect? If not, then what mitigation measures are required?

- Set up monitoring programmes to:

  - identify change and trends

  - identify when a certain tolerance level is exceeded.

Ecological values

Marginal wetlands and marginal vegetation

Marginal vegetation is affected by water depth and flooding periodicity. Where water levels fluctuate over a wide amplitude, distinct zones of vegetation develop, reflecting the individual species' tolerances to the duration of submergence/ emergence (see Johnson and Brooke 1989). A survey of the lower Waikato lakes by de Winton and Champion (1993) documented the distribution of vegetation communities along a gradient of decreasing water depth and flood periodicity (Figure 13).

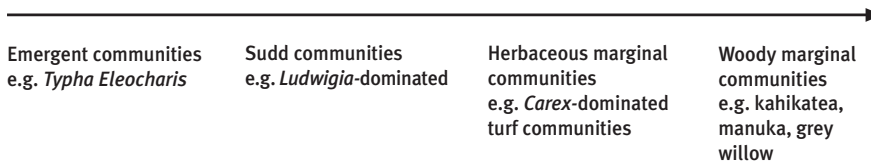Decrease in water depth / flood periodicity
(assuming low stress /disturbance)

→

| Emergent communities e.g. *Typha Eleocharis* | Sudd communities e.g. *Ludwigia*-dominated | Herbaceous marginal communities e.g. *Carex*-dominated turf communities | Woody marginal communities e.g. kahikatea, manuka, grey willow |

Figure 13: **Changes in vegetation with decreasing water depth and flood periodicity in lower Waikato lakes.**

Source: Reprinted from de Winton and Champion 1993.

Regulating water levels in lakes can have major impacts on marginal wetlands and vegetation. Changes in water depth and fluctuations produce changes in disturbance patterns through wave and flood actions, but also a different oxygen status and rates of carbon and nutrient processing in sediments (Champion and Shaw 2000). These changes alter the levels of stress and disturbance, and can lead to changes in the composition of the vegetation. For example, in the Netherlands, Coops and van der Velde (1996) report a change from diverse marginal vegetation dominated by *Schoenoplectus, Scirpus* and *Phragmites*, to *Typha* as a result of reduction in water-level fluctuation.

Any decision to alter lake water levels needs to carefully consider the effects on marginal vegetation. For example, in the summer of 1989/90 at Lake Whangape in the Waikato a natural sill was removed, which reduced the lake height minima. This exposed large areas of the shoreline, creating conditions suitable for the development of the turf communities discussed in section 1. Several nationally endangered and rare species were found in these turf communities, having grown from seedbanks that were likely to have represented vegetation from an earlier time in the lake's history (Champion et al. 2001).

In 1999 a new sill was installed to restore the minimum lake level, based on water-level records between 1968 and 1983, when minimum water levels must have been higher than in the past. The increase in minimum lake level is likely to decrease available littoral habitat for turf communities by up to 65% (Champion et al. 2001) and potentially reduce the numbers of individuals of rare species. The new sill will, however, benefit marginal emergent vegetation, such as *Typha orientalis* and *Eleocharis sphacelata* (as long as grazing is restricted), which are adapted to less variation in water level and a higher minimum water level. Development of large beds of emergent vegetation will also produce other benefits, such as improving the water clarity and reducing nutrient inputs to this turbid eutrophic lake (Champion et al. 1996).

Controlling macrophytes

Macrophytes are a key component of the ecosystem around the edge of most New Zealand lakes. They provide a complex, three-dimensional substrate for periphyton (on which most macroinvertebrates feed) and a refuge for invertebrates and fish; they also support water fowl, stabilise substrates, promote settlement of catchment-derived suspended solids, and remove nutrients entering lakes through groundwater and surface runoff. Excessive growths around the edge of lakes, however, can be aesthetically unacceptable and can cause problems for

recreation by restricting swimming and boating activities. In many cases introduced tall vascular species have replaced low-growing native species. Control of excessive growths has become a major issue in lakes where access is compromised, in hydro-storage lakes (for example, Waikato River lakes), and around boat ramps.

The distribution of introduced and native vascular plants in most lakes is largely determined by substrate suitability, the degree of exposure to wave activity, water depth and water clarity. Large changes in lake level (over 4 m) can potentially be used as a management option for controlling the growth of tall vascular species if the range plus the zone affected by wave activity exceeds the potential depth range for growth.

Although lake-level fluctuations have not been routinely used to control excessive plant growth in New Zealand, there are examples that suggest such an option is possible. Lake Moawhango on the central volcanic plateau and Lake Hawea in the South Island both experience fluctuations of over 10 m. The aquatic vegetation in Lake Moawhango is restricted to three species of macroalgae with no vascular plants, and this has been attributed to the large lake-level fluctuations. Similarly, when Lake Hawea used to experience long periods with large lake-level fluctuations, most of the lakeshore was devoid of vascular plants. These examples are deep lakes, but the observations suggest that actively managing lake levels over a greater range than may occur naturally in small, shallow lakes could be one way to limit nuisance aquatic weed growths around the edge. Careful consideration of the effects on other aquatic and wetland communities would be required, however, before proceeding with this as a management strategy.

Controlling sediments

Controlling sediments as an aspect of lake management is not usually possible – even if desirable – without special and often expensive structures, either built specifically for the purpose or which control sediment as a side-effect. For example, the Clyde Dam impounds the Clutha River in Lake Dunstan, and thereby removes the substantial sediment load carried by the Shotover River. Previously this was deposited further down-river in Lake Roxburgh.

As a (perhaps) unique example, the Mararoa River was diverted into Lake Manapouri by the Manapouri control structure (Mararoa Dam) as part of the Manapouri – Te Anau hydro-electric development, and it has proven possible to remove sediment from the river as a way to mitigate its undesirable impact on Lake Manapouri. The Mararoa River was predicted to add about 7.5% to the Manapouri – Te Anau water resource. Below the Mavora Lakes it traverses land recently intensively developed for farming, where it picks up a substantial sediment load, amounting to about 33,000 cubic metres annually, essentially from bank erosion when in flood. The diversion of the Mararoa River into Lake Manapouri meant that during floods, sediment-laden, highly discoloured water, sometimes also carrying noxious weeds (broom and gorse bushes, for example) and dead stock, was discharged into the otherwise pristine water of Lake Manapouri in Fiordland National Park (Figures 14a and b).

Figures 14a & b: Dirty, silt-laden water of the Mararoa River in flood, flowing past Pearl Harbour, Manapouri, during a severe flood in April, 1975 (a), en route to the lake entrance where, as on 31 October 1977, (b) it sank below the warmer water of the lake and so left a limited area of dirty water on the surface. Note, at other times, when the river is warmer than the lake water, the surface extent of dirty water can be much greater.

Photos: Alan Mark (photo 14a), Les Hutchins (photo 14b)

Ministerial approval was given to resolve this issue in consultation with the station operators, who established turbidity and flow recorders in the Mararoa River just up-river of the control structure. Agreement was reached between the Guardians and ECNZ that a turbidity limit of 30 NTU (Nephelometric Turbidity Units) at this site was appropriate, and the flow corresponding to this turbidity value was used to trigger gate opening, regardless of the level of Manapouri, to release the dirty Mararoa water through the gates for discharge down the lower Waiau River – its natural course. This procedure has generally worked well (although when Manapouri's level is very low some dirty water may still reach the lake, and some people down river resented receiving only the dirty Mararoa water), and has been incorporated into the resource consents, together with a compensation flow of clean water, referred to earlier.

The resource consents also provide for the installation, operation and maintenance of a pass for both trout and native fish in the Manapouri control structure, as well as 'recreational flows' of up to 45 cumecs, to be released monthly for a period of 24 hours, between October and April. There is also provision for the passage of migratory fish through the Waiau River mouth, by ensuring two flows per year of not less than 35 cumecs for 24 hours during June and August, and one flow of not less than 150 cumecs for 24 hours during March to May inclusive, and September to November inclusive (provided the lake management guidelines are not jeopardised).

Recreational requirements

The shallow zone of lakes is important for a range of recreational pursuits, including fishing, boating and swimming. Lake-level fluctuations can have a significant impact on the reputations of lakes for these activities. Recreational requirements have rarely been taken into account in lake-level management, but there are a growing number of cases where they are considered as part of consent conditions.

Lake Otamangakau, for example, a man-made lake in the central North Island, is renowned for trophy-sized brown trout. Surveys of angler satisfaction were conducted, which included the effect of lake level. Based on those results, and findings from ecological surveys, guidelines were developed to enhance recreational fishing (Dedual 1999). It was recommended that the lake be kept as close as possible to a set level from October to May (the legal fishing season). From June to September a lower level was proposed to expose macrophytes to frost, thus providing a weed-free zone for fly-fishing from the shore the following spring and summer.

A further consideration for lake-level management is the location of the 'drop-off'. If levels are low in summer, then fishers can fly-fish in waders at the edge of the drop-off where trout tend to feed; but if the reverse happens and levels are high in summer, this region is not readily accessible.

Beach access is another issue, which can be particularly important when lakes are first raised or lowered. The loss of beaches was a concern when Lake Rotoaira was raised 0.6 m in the early 1970s. Lowering of lakes can also have significant effects – sometimes beneficial. For example, lowering Lake Waikaremoana by 5 m in 1946 resulted in the loss of shallow, safe swimming and fishing beaches. However, there have been positive benefits through the creation of extensive flat areas that

are now used as part of the Lake Waikaremoana walking track. The gentle slopes have also provided additional boat launching and landing areas, and improved public access around the lake.

Landscape, visual and shorelines

Promotion of lakeshore restoration

Lake management guidelines were applied to Lake Monowai, Fiordland National Park, by the Lake Guardians, after responsibility for its management oversight was given to them by the Government under the Conservation Law Reform Act 1990 (see above). This lake was raised about 2 m in 1926 as part of its development for hydro-electric generation. A variable margin of dead trunks, stumps and root plates (Figures 15 – 17) from the original shoreline forest persisted around much of the lakeshore, despite Government staff removing many trunks from the lower, more accessible and visible part of the lake in the late 1960s in response to increasing public concern for the proposed raising of Lake Manapouri[7].

Figure 15: A section of the Lake Monowai shoreline where trees were killed as a result of a 2 m rise in lake level in 1926. The trees were not removed, and persisted as a fringe of variable width around the lakeshore. (December 1969.)

Photo: A Mark

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[7] See Case study one: Lakes Manapouri and Te Anau for detail (page 58).

Figure 16: The bottom end of Lake Monowai after removal of dead tree trunks from the accessible lower half of the lake in response to strong public criticism over the proposed raising of the level of nearby Lake Manapouri. Warning signs for boaties were still required. (April 1970.)

Photo: A Mark

Figure 17: Dead tree stumps and root plates persisting on the shore of Lake Monowai among jointed rush (*Leptocarpus similis*), which has established under the new regime of lake management since the lake was raised about 2 m in 1926. (April 1970.)

Photo: A Mark

Results of a shoreline vegetation survey and stability assessment commissioned by the Guardians in 1991–92 (Johnson 1991; Kirk 1992) indicated that zones of shoreline vegetation were being re-established and most beaches were either actively growing or dynamically stable, and that the stripping of former forest soils and old beach ridges was substantially complete. Re-establishment of natural-looking shores and vegetation was most advanced on steep shores of hard rock, and progressively less so at beaches, on steep soft-rock shores where some undercutting was still occurring at higher lake levels, and on gentle shores of bay-heads and deltas.

The conclusion from these studies was that readjustment of shoreline features to the new regime of lake management was well advanced, to the extent that this could be further facilitated by retaining the current operating pattern. Accordingly, management guidelines were developed for Lake Monowai by the Guardians in 1996, in consultation with Johnson and Kirk, on the same general basis as those for Lakes Manapouri and Te Anau, using the record of lake levels for the period 1977–96. These guidelines have been formally adopted by the operators of the power station. Re-monitoring in 2000 of the shoreline vegetation and beach-monitoring sites, established as part of the initial surveys in 1991–92, has indicated that lakeshore rehabilitation is continuing.

Developments on the shoreline

Developments or construction on or near the shores of lakes should be approached in the same way as proposed developments on oceanic shores. Although lakeshores are not subject to coastal plans or the New Zealand Coastal Policy Statement, the same concerns and issues apply. Significant urban development on several New Zealand lakes warrants special management consideration, and should be noted by the appropriate regional and district councils. An assessment of environmental effects should be carried out for subdivisions, buildings, roads or infrastructure. This assessment should include 'coastal' hazards and a description of appropriate mitigation measures.

Hazards to consider include long-term and short-term erosion, storm-wave run-up and flooding inundation, subsidence of unconsolidated or incompetent sediments, and sub-aerial weathering of cliffs or hillslopes. Landscape and amenity values should also be considered, as should cultural, social and economic factors.

A proposed development should identify the physical processes at the site, set up a monitoring network and identify any hazards. Building set-back distances and minimum floor levels should also be identified.

Management of coastal lakes

The management of coastal lake levels is concerned mainly with flood management of the hinterland of the lakes and of the lake catchments. Coastal lakes such as Lake Ellesmere and Wainono Lagoon in Canterbury are managed for these purposes, with the latter an integral part of a wider flood and farmland drainage network (Pemberton 1980). The low-lying coastal lakes are also important wetland habitats, for nesting and as staging points for bird migration. Hemmingsen (1997) discusses the management of Lake Ellesmere in detail, and describes the pre-European shoreline extent. Artificial opening of the lake to the

sea at Taumutu predates European colonisation, but is now carried out for flood management of the surrounding farmland. Drought can also play a major role in determining the lake levels, as was the situation in April/May 2001. This caused extremely low water levels, which affected the early part of the duck-hunting season.

Managing these lakes may also include considering coastal processes on the seaward side of barrier beaches that enclose a number of them (such as Lake Ellesmere, Washdyke, Wainono and Waituna Lagoons). These barrier-enclosed coastal lakes have been termed 'Waituna-type' lagoons by Kirk and Lauder (2000). They note that the water body is typically fresh or brackish, and is more usually closed from the sea than open to it. Breaching of the barrier between the lake and the sea can be a significant coastal hazard, as occurred at Wainono in 1985 when 500 ha were flooded with seawater after the barrier beach was overtopped and breached by storm waves.

Management of peat lakes

In parts of New Zealand, particularly the Waikato, considerable resources have been put into converting peatland into pasture. Conversion involves draining the peat, causing shrinkage and decomposition: peat can contain up to 95% water by weight, and 95% of the remainder is carbon, which decomposes when exposed to air. As a result shrinkage can be rapid, up to 200 mm/year after initial cultivation (Environment Waikato 1999). This can have a major effect on peat lakes, reducing the amount of humic acid entering them and lowering water levels (Champion 1997). The former Lakes Serpentine and Rotomanuka are examples of lakes reduced in area as a result of peat shrinkage. In fact the water levels in these lakes have dropped to such an extent they are now divided into a number of smaller lakes (Stockdale 1995).

The most important factor in managing peat lakes is to retain the natural hydro-logical regime. For peat lakes within unmodified peat bogs or fens, the best way to retain the natural hydrology is to prevent drainage of the adjacent bog or fen. For peat lakes within farmed landscapes, Stockdale (1995) and Thompson and Green-wood (1998) suggest the following management guidelines:

- retain precipitation by blocking outflows

- prevent direct inflow of water from drains

- maintain a high groundwater level with limited fluctuations in the peat margins adjoining the lakes to encourage peat regeneration

- plant indigenous vegetation around the margins to prevent invasion of scrub weeds such as grey willow

- establish a hydrological buffer zone around the lake and its margin; the width of the margin around the peat lake will depend on the local hydrological conditions and is likely to be at least 50 m.

CASE STUDY ONE: LAKES MANAPOURI AND TE ANAU

The Lakes Manapouri – Te Anau case is unique in New Zealand. A prolonged (13-year) public debate and protest followed the Government's decision to sign a formal agreement, in 1960, with a multi-national consortium, now known as Comalco. The agreement allowed the consortium to raise the levels of Lakes Manapouri and Te Anau, in Fiordland National Park, to maximise hydro-electric development for an aluminium smelter the consortium proposed to build at Tiwai Point near Bluff. (The only constraint was a condition that Te Anau township was not to be threatened.)

The debate gathered momentum through the 1969 general election and an ensuing formal commission of inquiry, which, among many relevant issues, reported that "a considerable and highly responsible section of the community … is deeply concerned at the proposed raising of the level of Lake Manapouri" (Manapouri Commission 1970). It also expressed concern with proposals for lakeshore clearing and an unacceptable threat of managed high lake levels to Te Anau township (see Peat 1994). A record-breaking 'Save Manapouri' petition attracted 264,907 signatures in 1970 (almost 10% of the country's population at the time). The controversy climaxed with the 1972 general election, which resulted in a change of government, based largely on environmental issues and particularly the Lakes Manapouri – Te Anau issue. The Manapouri – Te Anau Lake Guardians were appointed following this election.

Public concern was heightened by localised collapse of the Manapouri shoreline in Surprise Bay (see Figure 9) just two months before the election, which was associated with the lake level being dropped up to 85 cm below its recorded minimum level (179.92 m) for a short period (25 days) – much less than was legally permitted. After the election, with the change of government, Labour, under Prime Minister Norman Kirk, honoured its pre-election commitment not to proceed with lake raising. In addition it established the Guardians of Lakes Manapouri and Te Anau from among those who had spearheaded the campaign. Their terms of reference and role are outlined elsewhere in this publication. Further details on the case, which is generally considered to be New Zealand's first great conservation success, in terms of both conflict resolution and the successful integration of nature conservation with sustainable development of a major natural resource within a national park, are in Mark et al.(2001) and are summarised below.

Lake management guidelines:
Case study on Lakes Manapouri and Te Anau

A summary of this case, including background, is given in Case study one (above). Because of the complexity of the case, its high public profile and resolution integrating nature conservation with hydro-electric development in a national park and world heritage area, a more comprehensive discussion of the approach is given in this section.

Under the terms of reference established by the Government in 1973 for the then newly established Guardians of Lakes Manapouri and Te Anau (and repeated in

Part IIB of the Conservation Law Reform Act 1990), 'Guardians of Lakes Manapouri, Monowai and Te Anau' S 6X (2a), their role is:

> *To make recommendations to the Minister [of Conservation] on any matters arising from the environmental, ecological, and social effects of the operation of the Manapouri – Te Anau hydro electric power scheme on the townships of Manapouri and Te Anau, Lakes Manapouri and Te Anau and their shorelines, and on the rivers flowing in and out of those lakes, having particular regard to the effects of the operation on social values, conservation, recreation, tourism, and related activities and amenities.*

A similar clause (b) referred to Lake Monowai in the 1990 legislation. Clause (c) states:

> *To make to the Minister [of Conservation], and to the Minister responsible for the administration of the Manapouri – Te Anau Development Act 1963, recommendations on the operating guidelines for the levels of Lakes Manapouri and Te Anau, for the purposes of Section 4A of that Act.*

This section (4A) was contained in the 1981 amendment of the 1963 Act, and replaced the original lake raising and lowering clauses. It referred, among other things, to the Minister, from time to time promulgating:

> *by notice in the Gazette, operating guidelines, submitted to him, by the Guardians of Lakes Manapouri, Monowai and Te Anau, for the levels of those lakes aimed to protect the existing patterns, ecological stability, and recreational values of their vulnerable shorelines and to optimise the energy output of the Manapouri power station.*

Provisional lake management guidelines were developed by the Guardians in 1973 and modified periodically in relation to the completion of various aspects of the hydro-electric project, notably the Te Anau and the Manapouri control structures, as well as the effects of several events and the results of additional research commissioned by the Guardians.

From the outset the Guardians emphasised the need to recognise three categories of operation within the natural range of levels of each lake, recorded daily since 1932: 4.8 m for Manapouri and 3.5 m for Te Anau. These categories were referred to as the high, main and low operating ranges (Figure 18).
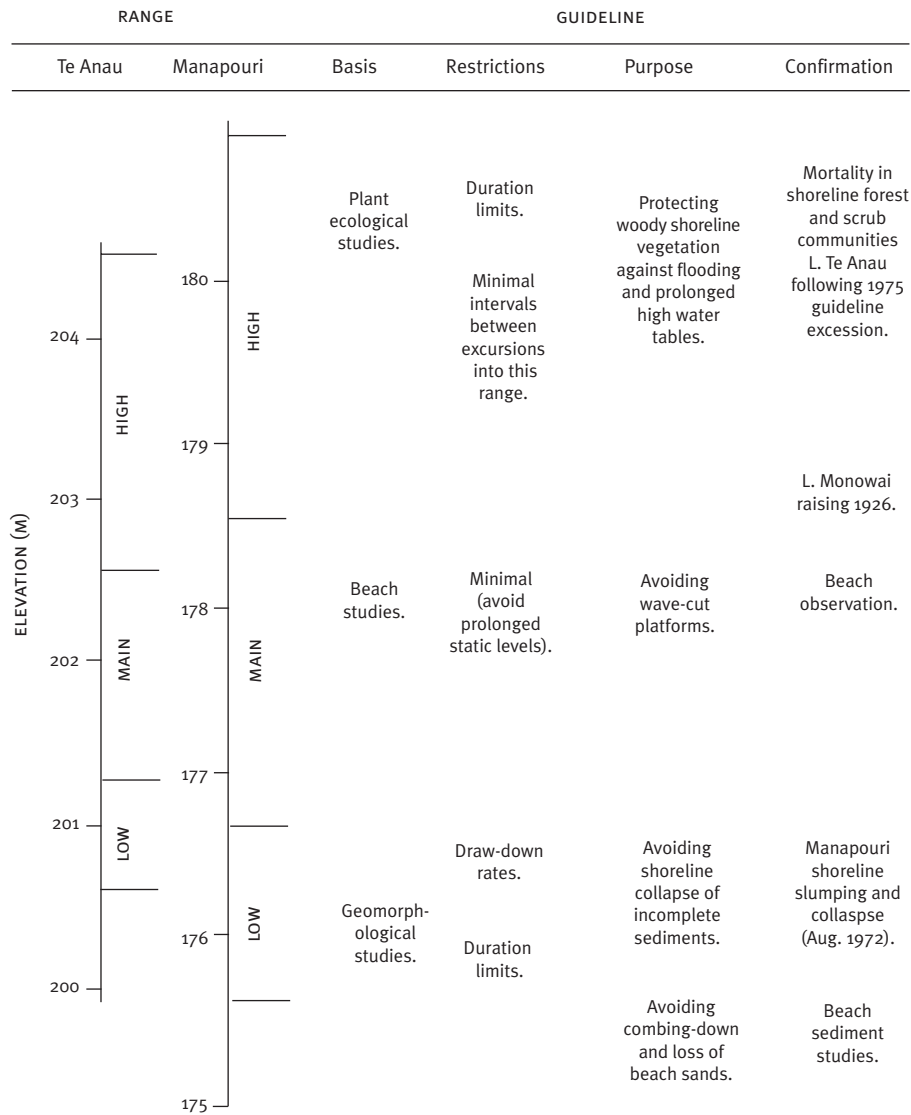
RANGE		GUIDELINE			
Te Anau	Manapouri	Basis	Restrictions	Purpose	Confirmation
HIGH (204, 180, 179)	HIGH	Plant ecological studies.	Duration limits. Minimal intervals between excursions into this range.	Protecting woody shoreline vegetation against flooding and prolonged high water tables.	Mortality in shoreline forest and scrub communities L. Te Anau following 1975 guideline excession.
MAIN (203, 202, 178, 177)	MAIN	Beach studies.	Minimal (avoid prolonged static levels).	Avoiding wave-cut platforms.	L. Monowai raising 1926. Beach observation.
LOW (201, 200, 176, 175)	LOW	Geomorph-ological studies.	Draw-down rates. Duration limits.	Avoiding shoreline collapse of incomplete sediments. Avoiding combing-down and loss of beach sands.	Manapouri shoreline slumping and collaspse (Aug. 1972). Beach sediment studies.

ELEVATION (M)

Figure 18: **Summary of the management guideline for Lakes Manapouri and Te Anau. The high, main and low operating ranges for each lake are described in terms of elevation, basis, restriction imposed, purpose and confirmation.**

Source: Reprinted from Mark et al. 2001.

- The *high operating range* embraced about the upper third of the natural ranges of each lake, and attempted to deal with the tolerance limits to flooding of the woody shoreline vegetation. It considered two factors:

  - the maximum duration at any particular level within this range

  - the minimum interval between consecutive floods of a particular level within this range, necessary to allow adequate drainage of the water table.

- The *low operating range* embraced less than the lower third of the natural ranges and considered the stability of the shoreline sediments, which had been shown to be vulnerable to slumping of fine till and to collapse at those

beaches with narrow shelves overhanging deep water (see Figures 9 and 10). Draw-down rates were specified, plus maximum periods for levels at various intervals within this range.

- The *main operating range* – also occupying about one third of the lakes' natural ranges – was without restrictions apart from a request to avoid static levels for long periods, which usually cause the development of wave-cut platforms. Particular values for the high and low operating ranges were derived from the most extreme event over the 37-year record of natural levels, while recognising the importance of optimising the use of the water resource for hydro-genera-tion. Simple ratios of 'minimum interval / maximum duration' were specified in the high operating ranges for flood periods less than the maximum durations specified in the guidelines. A further requirement was that the annual running mean lake level be within the main operating range for each lake.

Exceedance of the provisional guidelines for Lake Te Anau, associated with the floods of 1975 and concurrent attempts by the station operators to minimise damage to the Manapouri control structure (then under construction and in a vulnerable situation), provided important verification of the guidelines for the high operating range (Mark et al. 1975). An example of the effect on shoreline forests of high operating levels being exceeded during floods is shown in Figure 19. This situation, together with the detailed study of the lakeshore sediments and geomorphology (Pickrill 1976), which was particularly relevant to assessing lake management in the low operating range (see Figure 18), was significant in the Government's formal acceptance of the 1977 lake management guidelines as "indicative rather than absolute rules", and as "an acceptable compromise between protecting the unique environmental and ecological features of the lakes system and maximising the energy output of the Manapouri power station."

Figure 19: **Dead trees, mostly silver beech, in shoreline forest on the fan of the Delta Burn, South Arm, Lake Te Anau, killed as a result of the high operating guidelines for the lake having been exceeded between April and December 1975 and April 1976.**

Photo: A Mark

The guidelines were gazetted in 1981 (3 December, p.3651) and, subject to the provision for periodic review, again in 1993 with minor modifications based on information from lakeshore monitoring (No 58; 29 April, pp. 1084–5). Further minor changes are planned on the basis of more recent events and a longer lake level record.

Recent modelling of the lake management guidelines by the Manapouri power station operators (ECNZ and Meridian Energy), together with the relevant hydrological situation in the Manapouri – Te Anau catchment, has resulted in a steady refinement and improvement in guideline compliance over time. The current MANTAray model was custom made for the Manapouri – Te Anau system. MANTAray uses real-time data from the GCMS (generation control management system) and applies lake management guidelines to the data. This displays plots of real-time information for each lake, with the lake levels and various discharges, together with any caveats required by the guidelines, particularly in relation to duration and/or draw-down rates within the high and low operating ranges respectively (Peter Mason, Meridian Energy, personal communication; see Figure 20). These predictive aspects have presumably been a factor in the concurrent reduction in frequency of guideline exceedance.

Results of periodic independent monitoring of shoreline vegetation and beach sediments, initiated by the Guardians in 1973, have been invaluable in assessing the effects of lake management against the legislative requirements to minimise adverse effects. To quote Kirk (1996), contracted to provide independent monitoring of the Manapouri and Te Anau beaches:

> *I think the long record now available there is unique in both management and scientific terms. It shows some extremely interesting and important aspects of the environment, not least how beaches behave longer term and how they respond to and recover from major 'traumas' like earthquakes and floods of 1988, meanwhile being under continuous human management of water levels. In my view, the long record also serves to demonstrate to science and the community alike how folk and agencies can come together to make an environmental success story such as the management of Lakes Manapouri and Te Anau has been.*
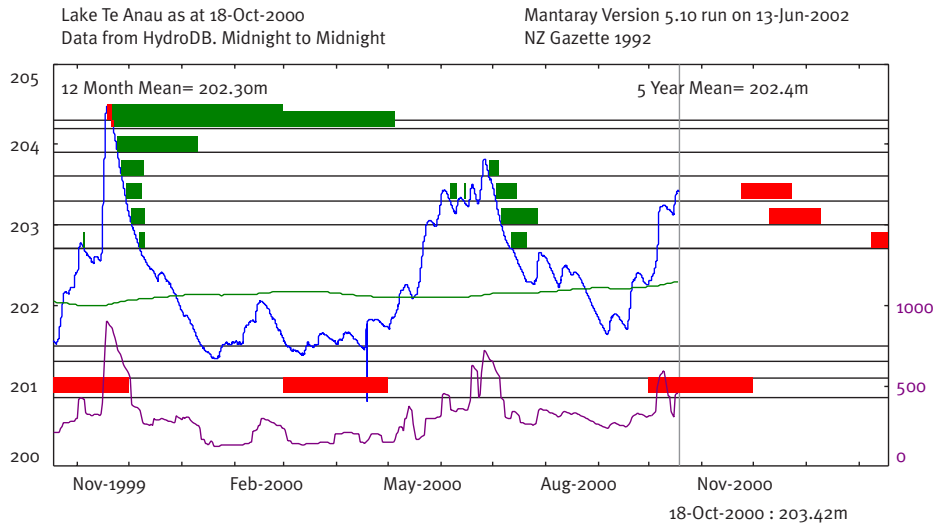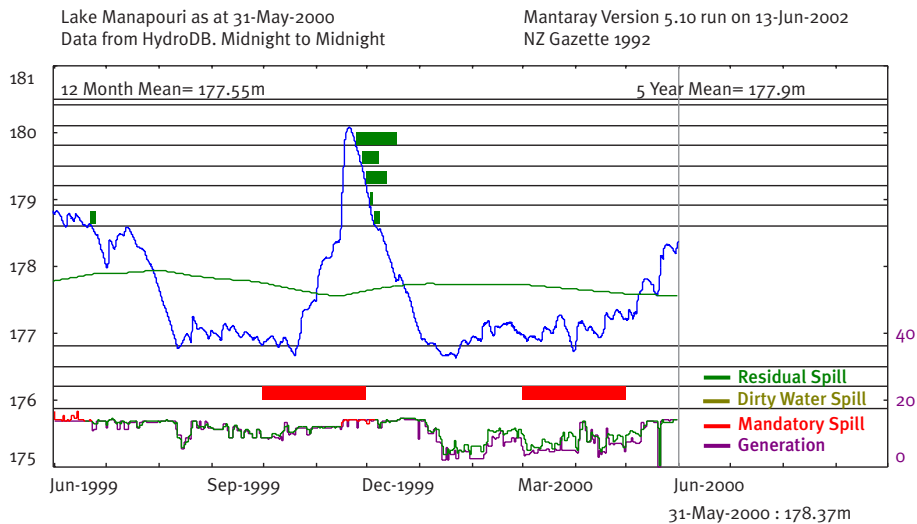
Figure 20: **Print-outs of the MANTAray models for Lakes Te Anau (top) and Manapouri (bottom), Fiordland, showing the various aspects recorded.**

Notes: Time in months is on the horizontal axis, while guideline parameters are given (in red) down the right-hand side. Continuous lake levels are shown (blue line) in relation to the main operating range (central area), the high operating range (top section) and low operating range (bottom section), with lines in each drawn at 0.3 m intervals above and below the main range. The annual running mean values are shown (in green) within the main range for each lake (scales for elevation are on the left margins) in relation to its long-term mean value (top left). Flows out of Te Anau (upper Waiau River) are shown (purple line) at the base (scale in cumecs on the right margin), while flows for Manapouri generation (purple line) and mandatory spills, associated with high lake level (khaki line) or high (dirty water) flow in the Mararoa River (red line), or residual spills (green lines), are scaled in GWh. The three red-hatched blocks near the base of the diagram depict the equinoxial periods (when strong winds often occur), when low lake levels are to be avoided. The hatched blocks of variable length associated with levels in the high operating range for both lakes represent durations when the lake level cannot return to the particular range without exceeding the guideline value for that range.

Source: Graphs supplied by Meridian Energy.

BOX 5: MANAGEMENT GUIDELINE SUMMARY

The RMA adopts an integrated and holistic approach to the use and management of its natural and physical resources. Provisions and definitions in the Act have been used to devise a checklist for assessing effects.

A best endeavours approach was considered more appropriate in the Manapouri case rather than inviolate rules. This allows for full reporting and consultation on any breach of the rules.

Various approaches have been taken to consent applications, ranging from the single-purpose approach in 1988 with the Tongariro Power Development application, to a working party approach involving all interested parties and compromises, as was the case with recent Manapouri– Te Anau and Waikaremoana applications.

Fluctuating lake levels limit the distribution of nuisance aquatic plants, and in cases where fluctuations are over 7–10 m, may completely eliminate vascular plants. This potentially offers a management technique to enhance recreational activities or improve lakeshore aesthetics.

Recreational opportunities can be affected by fluctuating lake levels, but active management can also be beneficial. Options include fluctuating levels that will provide weed-free zones for fly-fishing, and keeping levels high during fishing seasons to provide wadeable areas.

A summary of the management guidelines for Lakes Manapouri and Te Anau is provided in Figure 18. The high, main and low operating ranges for each lake are outlined in terms of elevation, basis, restriction imposed, and confirmation for each range.

Monitoring requirements

Purpose and criteria

Monitoring lakeshore and aquatic vegetation, and soft sediments at a series of adequately representative sites, is essential for an objective assessment of the environmental impacts associated with the management of lake levels. Long-term monitoring of aquatic macroinvertebrates and fish communities has also been considered, but interpreting distribution and abundance patterns is difficult and monitoring is time consuming and expensive. Good relationships have been demonstrated between the distribution of macroinvertebrate communities and macrophyte composition and biomass (see James et al. 1998; James, Weatherhead et al. 1999; James, Champion et al. 2000). Based on these studies, it is recommended that monitoring of macrophyte communities be used to indicate potential changes in aquatic communities. Most of this section therefore focuses on vegetation.

Ideally, the monitoring of lakeshores and the littoral zone should be established before any development and when the lake level is relatively low. Re-monitoring should be carried out when the level is equally low, so that the surveys are comparable and the full range of lakeshore communities is readily accessible. Several key points that apply to any monitoring of vegetation apply equally to lakeshore (see Stewart et al. 1998) and littoral zone monitoring. These include the:

- need for clearly defined and appropriate objectives

- use of methods appropriate to the objectives and type of vegetation involved

- need for careful site selection and an appropriate sampling strategy

- importance of adequate field marking for relocating plots and transects

- detailed recording of location, objective, methods and recording format so that re-surveys are possible, even many years later, possibly involving different people

- choice of an appropriate sampling interval, which will normally be dictated by the rate of change expected or that actually occurs, the detail required, and the resources available (the most appropriate interval may not be apparent until after initial re-surveys, and the fluctuating rates of vegetation change may prompt alteration to the monitoring frequency at any stage)

- use of well-trained and dedicated people, capable of careful and often tedious field measurements and data interpretation

- need to take care to minimise the physical impacts of monitoring.

Methods for locating, marking and sampling the monitoring sites are obviously important in obtaining useful and relevant information. Transects established normal to the shoreline and covering the full range of lakeshore features likely to be affected by the proposed lake-level management, and accompanied by photographic coverage from known sites, have been found to be the most satisfactory method of monitoring.

Ideally, monitoring should be initiated prior to any artificial control of lake levels so that a natural baseline can be established. It is important to realise that even natural shorelines are dynamic – not static – environments, which are ever changing in response to a range of ecological factors in ways that must be appreciated and understood in order for changes associated with lake-level control and management to be evaluated.

The monitoring of shoreline vegetation and soft sediments at Lakes Manapouri and Te Anau began either before (Te Anau) or soon after (Manapouri) these lakes came under control for hydro-electric generation in the early 1970s. Similar monitoring of another Fiordland lake, Monowai, began in the early 1990s, more than 60 years after its level was raised about 2 m. This monitoring has been invaluable in the development and refinement of appropriate methods for lakeshore monitoring elsewhere. They will therefore be explained in some detail, as an example, in the following section.

Monitoring procedures

Location

The number and location of monitoring sites, adequate for the particular purpose, should normally be decided after a comprehensive ecological survey of the lakeshore. In the case of Lakes Manapouri (area 142 km^2 ; shoreline 170 km) and Te Anau (area 352 km^2; shoreline 520 km), surveys of shoreline vegetation (Johnson 1972a, b; Mark et al. 1972) and beach sediments (Irwin 1974; Pickrill 1978a) were followed by establishment of 10 permanent transects at Manapouri and 16 at Te Anau for vegetation monitoring in 1973–74 (Johnson 1974). These were later (1999) modified to 15 for each lake. Some 89 beach-profile transects were permanently marked on Lakes Manapouri and Te Anau, from which a smaller representative sample of up to 20 sites per lake could be selected for re-survey as and when required (Kirk and Single 1988).

For the smaller Lake Monowai (32.5 km^2), 12 permanent transects to monitor shoreline vegetation were established as part of a vegetation survey in November 1990 (Johnson 1991), and 10 were set up to monitor non-rocky shoreline sites as part of a shoreline stability assessment survey in January 1992 (Kirk 1992).

In addition, Lake Hauroko (68.3 km^2) was established as a baseline study area for lakeshore vegetation monitoring in relation to the managed Fiordland lakes. Its shoreline vegetation was surveyed in 1991, when eight permanent transects were also established (Johnson 1997a; 1997b).

In Lake Waikaremoana (56 km^2), 10 horizontal transects from the high-water level to the bottom of the macrophyte zone were established and surveyed between 1982 and 1988. Although the lake was originally lowered in 1946 (see Case study two, page 74), these later surveys do provide some baseline data for any further changes. These sites were resurveyed during 1996–98 leading up to the consent application, and will be resurveyed at five-yearly intervals as part of the consent conditions. A number of long-term sites for aquatic vegetation have been established for a number of other New Zealand lakes, including Lake Hawea, where 13 sites were established in 1982 (Clayton et al. 1986), Lake Coleridge (James et al. 1998), Lake Rotoaira (James, Boubee et al. 1999) and Lake Taupo (James, Champion et al. 2000).

There has been very little long-term monitoring of macroinvertebrate communities in lakes used for hydro-electric storage. A single site with a transect line perpendicular to the shore was established in Hautaruke Bay, Lake Waikaremoana, by Mylechreest (1978) in 1975, and this was resurveyed in 1996–98 along with an additional, more exposed site. Three sites, covering a range of conditions for exposure to wave activity and proximity to urban areas, were sampled monthly over 16 months in Lake Taupo as part of the study for Mighty River Power's consent application (in preparation). This seasonal survey was limited to the cobbled habitat at 0.5 m water depth and included periphyton biomass and community structure (James, Champion et al. 2000). Three depths were also resurveyed at these sites, along with extensive macrophyte surveys, on two occasions since 1998. Surveys of the macroinvertebrate community were also carried out on Lake Coleridge in 1995–96 along two transects and seven depths on three occasions to determine recovery rates following low lake levels (James et al 1996).

Site marking

Transects should be permanently marked, where possible, and identified so as to maximise the ease of relocation. Stout metal stakes such as warratahs should mark each transect, the outer stake for terrestrial vegetation being located at or near the outer edge of the shrub zone (if present), and the second to shoreward of it, at the inner margin of the transect, well within the shoreline forest (if present). The alignment of the transect should be normal to the shoreline and recorded with a compass, together with the distance between the two stakes. A GPS reference should also be recorded for the outer stake, as well as any prominent landscape feature to aid future relocation. (Note: the stakes should not be located beyond the shrub zone in shorter herbaceous vegetation of the 'intertidal' zone because of the hazard they present to lake users, particularly boaties, and the likelihood of their removal.) All transects should be adequately identified with a firmly attached metal (aluminium or stainless steel) label, and inscribed (with a vibrating engraving 'pen') as to ownership, purpose, and transect number, plus a 'Please do not disturb'.

Transects for aquatic vegetation can be relocated using shore markers or GPS. Depending on the recreational uses of the area, it may also be possible to put warratahs and permanent rope transects through macrophyte beds, but they need to be well positioned to avoid problems with boating and fishing activities. Transect lines put in Lake Waikaremoana were relocated 16 years later and provided an excellent baseline for assessing changes in depth range for various macrophyte species.

Sampling methods

Terrestrial vegetation monitoring

The sampling method used for monitoring shoreline vegetation (and beaches) of the Fiordland lakes, discussed above, is considered appropriate for forested lakeshores with well-developed zonation out to the sub-littoral macrophyte beds, and should be applicable to most lakeshores, with appropriate modification.

The recommended method for sampling shoreline vegetation is as follows.

1. Using a tripod-mounted surveyor's level and graduated staff, survey ground levels at appropriate (depending on the gradient) regular intervals along a tape, which is run from the origin metal stake to the water's edge. Extension out into the lake might be necessary in some circumstances, or incorporated into aquatic surveys (see below). The marker stakes or the current lake level (obtainable from the official staff gauge at the time, or subsequently from official sources) can be used as the datum point.

2. Record vegetation composition in plots located along the tape (left side when looking towards the lake), with contiguous 4 x 4 m plots used to sample:

   • trees (over 10 cm basal diameter): height, dbh (diameter at breast height) and estimated percentage cover, where appropriate, recorded by species

   • small trees (over 5 m tall and under 10 cm basal diameter): height, number of stems, and estimated percentage cover, where appropriate, by species

   • shrubs (0.3 – 5 m tall): number of woody stems and estimated percentage cover, where appropriate, by species

   • herbs and ground cover (herbs and all other plants under 0.3 m tall): percentage cover estimated in 1 x 1 m plots (at 1 or 2 m intervals, or contiguous, depending on the amount of variation present), nested adjacent to the tape in a particular part of the larger plot, and continuing adjacent to the tape where the transect extends lakeward, beyond the shrub zone. Extension of the transect beyond the lake edge will depend on the current lake level, conditions, and/or the objectives of the study (also see below for aquatic vegetation). Note: for the herb/ground cover monitoring, use of frequency records of species in a series of nested quadrats within the larger quadrat, is preferred by some researchers as being more objective.

3. Use a scaled profile diagram, embracing the 4 m wide transect and the main features of the ground surface and vegetation (including species), and the location of the two marker stakes.

4. Make a coloured photographic record along the transect line, with the tape in place, from a known or fixed point (preferably from the top of the outer marker stake or a measured distance from the outer stake or the lake edge) and height. Include in the view a small hand-held blackboard containing the site details and date. Other photographs from relocatable positions may also be useful.

The data should be recorded on standard forms and formatted electronically for storage and retrieval. The Landcare Research procedures or comparable methods are recommended:

• ground-cover data are entered in the PC-Transect format (Hall 1996)

• tree data in the PC-Diam format (Hall 1994a)

• small-tree and shrub data in the PC-Ustorey format (Hall 1994b).

All of these formats follow a similar style, with a 'header' line for each sub-plot, which contains site information such as transect and plot name, location, year and month, elevation and plot area. The header should be followed by lines of coded species names and attributes (height and diameter for trees, counts per plot

for small trees and shrubs, estimated percentage cover for herbs and ground cover). All data are archived in both hard copy and electronic form in the National Vegetation Survey (NVS) Database held by Landcare Research. A hard copy of the data is also deposited with the client company, together with an annotated copy of the photographic record (electronic and/or hard copy).

Aquatic vegetation

For surveys of aquatic vegetation, transect lines are laid out perpendicular to the shore by scuba divers, from the high-water mark down to at least 5 m below minimum water level and preferably to the bottom of the zone occupied by macrophytes. Note plant height and species at 1 or 2 m intervals, along with water depth. Record percentage cover of vegetation in 1 m^2 quadrats at regular intervals along the transect using a modified Braun Blanquet cover scale (Clayton 1983) where:

1	=	1–5%
2	=	6–25%
3	=	26–50%
4	=	51–75%
5	=	76–95%
6	=	96–100%.

Bottom limits for characeans are particularly useful and, if permanent transects or markers are set up, effects due to changes in water transparency and lake-level changes can be monitored. The depth distribution and limits for vegetation should always be normalised to mean lake level for comparison with other surveys on the lake. Where visibility is very low, grab samples can be used to determine the presence of species and community composition.

An aquatic plant database for lakes is archived and maintained by NIWA in Hamilton. This database contains records from over 100 New Zealand lakes, and is presently being developed to provide query-capacity to extract data for lake managers.

Aquatic animals

Macroinvertebrate and fish communities are rarely systematically monitored because of their wide distribution, mobility, sampling difficulties and the number of complex factors that strongly determine their abundance. The limited surveys that have been carried out on the effects of lake-level fluctuations on macroinvertebrate communities have involved sampling along transects using a variety of methods, depending on the substrate (James et al. 1998; James, Weatherhead et al. 1999). Biomass can be estimated by measuring dry weight of a sub-sample of the macroinvertebrates collected, or by measuring weights of different taxa and multiplying by abundance.

Year class strength (abundance of fish of same age) in fish populations can also be determined by external influences, such as the availability of spawning habitat in streams. The most effective method of monitoring the potential for changes in fish population is monitoring changes in habitat. However, interpretation is

complicated by lack of information on how these habitats are utilised. A comprehensive survey of the abundance of trout in a number of lakes, subject to a range of water clarity and variable lake-level fluctuations, has been carried out by NIWA using various netting techniques. Results have not yet been published, but are summarised in James and Graynoth (2001). Many of these aspects are covered in the *Lake Managers' Handbook: Fish in New Zealand Lakes*.

The only long-term systematic monitoring of fish populations we are aware of forms part of the consent conditions for Lake Waikaremoana. Fish and Game New Zealand Eastern Region has been operating a monitoring programme called Datawatch for over 13 years to monitor growth rates of tagged trout in the lake. This has been expanded under the consent conditions to include growth rate, based on length and otolith aging of angler-caught fish, along with trout abundance, using standard methods such as escapement counts or counts of spawning trout in tributary streams. The findings are reported annually to the Hawke's Bay Regional Council. Spawning runs have also been compared on three occasions in the Wairehu Stream, the major spawning stream for Lake Rotoaira, in the central North Island, as part of a study funded by Genesis Power. The Waiau Trust has also funded a PhD study to look at the effects of lake-level fluctuations on fish populations in the littoral zone of Lakes Te Anau and Manapouri.

Changes of procedure

With periodic monitoring or review, there may be a case for changing some aspects of the monitoring procedure at some stage – either generally or for specific sites – depending on circumstances or improved techniques. Such changes should not be made without careful consideration, and if carried out it is highly desirable to use both the old and new methods at the time of changing methodology so that continuity of records is assured. Problems have arisen in the past where there has been a switch from using percentage cover to group frequency to assess the ground cover along permanent transects. Results from these two methods are not comparable.

Monitoring intervals

Experience indicates that monitoring shoreline vegetation at five- to ten-year intervals is adequate, as well as whenever a particular event, such as management guideline exceedance, has occurred. The resource consents for Lakes Manapouri and Te Anau specify five-year intervals for these lakes (with Lake Hauroko included as a baseline), or if and when the lake management guidelines have been exceeded. Monitoring of littoral macrophytes (Wells et al. 1994) at five-yearly intervals, with similar criteria, is also a requirement of the consents applied to Lake Waikaremoana, along with event-driven monitoring if the lake level falls below 580.29 m asl.

Assessing monitoring information

Assuming re-monitoring has been conducted using the same methods as the original sampling, and the presentation of results has also been consistent, any changes to the shoreline and littoral zone need to be assessed in relation to an understanding of natural lakeshore and littoral zone processes, and the limits of acceptability of any changes that have been recorded (see Johnson 1988; Kirk and Single 1988; Johnson et al. 1997a; 1997b; 1997c; Dawe and Hemmingsen 2000; McQueen and Ryder 2000). Peer review of the re-monitoring reports might be

considered desirable by those responsible for overseeing lake management.

In relation to evaluating re-monitoring information, the report by RM Kirk, Geography Department, University of Canterbury, who was contracted to ECNZ to provide independent monitoring of beaches at Lakes Manapouri and Te Anau, is a good example. He reported (in 1996):

The beaches are generally in good condition … meaning that they display a range of essentially natural behaviour that is quite variable from place to place in quite readily understandable ways, i.e., they are not 'forced' in any way by the operating range and the manner which ECNZ staff handle it from day to day and year to year. In my view that is real management success because it is not simply an absence of adverse effects, it's the positive ability to promote essentially natural behaviour in the beaches.

Indicator species

Indicator species should be evaluated, either in the initial survey or during the course of the monitoring as additional information comes to hand. In the case of Lake Te Anau, this was provided from results of a detailed assessment of the differential mortality of plants from the shoreline forest and scrub following guideline exceedance in 1974, soon after provisional management guidelines were developed (see Mark et al. 1977).

Macrophytes have been identified as a key community within lakes and can be used as an indicator of ecosystem health and to set management goals. An example is Lake Coleridge, where Hawes and Graynoth (1997) suggested a management goal of a water depth range for macrophytes of at least 5–25 m. This would protect the natural ecosystem while allowing utilisation for hydro-power. Models relating bottom limits to water clarity and suspended solid concentrations could then be used to set thresholds for controlling the lake level and sediments from inputs, which would optimise water inflows for power generation while protecting ecological and fisheries values.

A suite of indicator aquatic macrophyte species is presently being developed by NIWA to monitor trends in ecosystem health of lakes as it relates to increased sediment and nutrient input from catchment activities and displacement by invasive species. The most useful indicators appear to be species and communities found below the wave-wash zone. Turf species in the shallow wave-wash zone are most likely to be affected by fluctuating lake levels, but they are very diverse. The community structure in this zone is largely driven by the size of the water-level range, the duration of high and low levels, and exposure to wave activity.

BOX 6: SUMMARY OF MONITORING REQUIREMENTS

Monitoring is essential for objectively assessing environmental impacts, but the objectives need to be clearly defined, the methods standardised and the sites made relocatable. Ideally, monitoring should be undertaken before development to provide before and after comparisons.

Sampling methods generally involve transects or profiles at sites representative of physical conditions and biological communities. Ideally these transects should extend from the lakeshore forest through the shallow turf communities, and preferably to the bottom of the aquatic zone occupied by macrophytes. Plots or quadrats are surveyed along a tape and can include species, abundance and cover. Monitoring intervals depend on the objectives but are generally at five-year intervals for vegetation.

Long-term monitoring of macroinvertebrates and fish communities is rarely carried out because of sampling problems, mobility, and the number and complexity of factors that determine abundance and distribution. Instead, monitoring of habitats that may be affected by lake-level fluctuations and/or plant communities is recommended, but monitoring of fish spawning runs should be considered in some cases depending on the lake values identified by the community.

Approaches to assessing impacts

Introduction

A range of methods is available for assessing the potential impacts of altering or maintaining lake-level regimes, given that there can be considerable natural variability. The first step should be careful consideration of what the values of the resource are (are there significant recreational, intrinsic, cultural, spiritual, social or development values that need to be considered?). The relative importance of these values needs to be assessed, and will depend very much on the lake involved. Man-made lakes, for example, may be highly valued for hydro-electric storage and recreational values (for example, Lakes Ruataniwha and Otamangakau), while Lakes Taupo and Manapouri have significant cultural and spiritual values as well as being important for recreation and hydro-electric storage.

Once the values have been assessed through wide consultation with the public and user groups, a description of the existing status of the natural ecosystem and the sensitivities of the lakeshore and its communities to changing lake levels is required. This section outlines some of the approaches that can be taken.

Hydrology and lake levels

Most lakes will have historical records from lake-level recorders, which can be used to examine the frequency distribution, extent (means, minima and maxima), seasonality and durations at different levels. In some cases, as at Lake Taupo, these records date back to the early 1900s. If lake levels have been managed, unregulated levels can be simulated using mathematical models of the lake's behaviour based on what would have been natural inflows and outflows. For example, the unregulated levels of Lake Taupo have been simulated since 1942 from inflows minus diversion inflows from other catchments in the Tongariro Power Development. Such simulations allow a comparison of natural versus managed lake levels in terms of extent, duration at certain levels and seasonality of fluctuations. This not only allows an assessment of the potential effects of regulation on lakes, but simulations of natural levels also give a basis for natural variability which can help to provide guidelines for levels that protect natural resources. This procedure has also been used for Lakes Manapouri and Te Anau, where daily lake levels have been recorded since the early 1930s.

Wave activity

Kirk et al. (2000) model extreme wave run-up levels (R_{max} and $R_{2\%}$) to assess the effects of extreme waves on the shore for different water levels and wave events. NIWA have also developed a computer model, LakeWave, which calculates wave heights and longshore transport potentials on lakes by adapting NARFET (a model that calculates wave characteristics on narrow-fetch water bodies) and wave run-ups by adapting the work by Kirk et al. (2000). The model was successfully used in calculating nearshore processes for Lake Taupo (Hicks et al. 2000). Student research in the Geography Department, University of Canterbury, has also investigated the applicability of LakeWave to a number of South Island high-

country lakes, and has digitised the shorelines of many of the New Zealand lakes for this purpose.

CASE STUDY TWO

Lake Waikaremoana is a large (56 km²), deep (zmax = 248 m) lake located in Urewera National Park. The lake was formed approximately 2200 years ago by a massive landslide, which dammed the Waikaretaheke River. The level was lowered 5 m in 1946 to supply extra water for hydro-electric generation. The lake is an important regional asset and is particularly valued for its cultural and spiritual values, as well as for recreation, fishing and walking tracks. Concerns were expressed during consent hearings in 1998 that lake-level changes under the managed regime could be having an adverse impact on shoreline erosion, the ecology and fisheries.

ECNZ (now Genesis), who operated the hydro-scheme up until 1999, carried out a full consultation process with interested parties, including local hapu, recreational groups, Department of Conservation, Fish and Game and the regional and district councils. Based on this extensive consultation, discharges have been set to replace the 'best endeavours' at levels above the normal operating maximum of 583.29 m above sea level because of heavy rains that occur in the catchment and natural lake dynamics. There is to be no controlled discharge at levels below 580.29 m. Before the latest consent application, controlled discharges were allowed after consultation with Hawke's Bay Regional Council. Extensive ecological studies concluded that extreme lows, below 580.29 m, had the potential to cause long-term damage to the littoral zone of the lake and were instrumental in restricting the permitted lower lake levels.

The importance of establishing good monitoring programmes was acknowledged by Genesis in their AEE, and the following programme is part of the consent conditions.

The consent holder shall:

1. *Terrestrial vegetation*
   Undertake annual surveys and reports of the terrestrial shoreline vegetation of Lake Waikaremoana. This will involve vegetation transects representing the six shoreline types (from Shaw 1998) plus an additional 14 around the lake and photopoints along the transects. Methods to be used are described in Johnson (1997). Event driven monitoring will be undertaken if levels exceed 583.29 m asl for more than seven consecutive days.

2. *Erosion*
   Set up a shoreline annual monitoring network along 20–30 permanently marked shore profile transects. These will include representative transects through the main shoreline 'types' and areas of shoreline erosion. Event monitoring to be undertaken if levels recede below 580.29 m for more than 25 days.

3. *Littoral ecology*
   Extensive surveys were carried out over three years and based on those findings, five-yearly monitoring of the macrophyte community will be under-

Lake structures

The assessment of lake structures is usually based on a visual assessment of the structure's integrity and the condition of the adjacent shoreline. Signs of failure of the structure and/or the adjacent shore not only indicate an immediate problem, but may be precursors of longer-term problems in the integration of the structure with shore processes. Guidelines in the form of a set of rules produced by the US Corp of Engineers have been presented earlier (section 2). These can be used not only for determining effective designs, but also to assess the wellbeing of existing structures.

It is especially important that structures do not adversely impact on natural processes. For example, boat ramps should not intercept longshore sediment transport if it results in erosion of the 'downstream' shore. Shore protection, such as walls and revetments, should not transfer erosion to the ends or alongshore of the structure.

Historical records

There have been a number of cases in New Zealand where lake-level regimes have been altered and the effects documented, both short term (years) and over longer time periods (decades). These examples give some insight into potential effects and can be used to predict what might happen under a particular scenario.

The normal operating range in Lake Waikaremoana for hydro-electric generation was lowered by 0.5 m in 1980 following a submission by the New Zealand Wildlife Service to lower summer levels to improve angling. Problems with low levels in 1982–83 compounded the effects, and the original operating level was reinstated in 1985. Comprehensive surveys were conducted during that time and showed that vascular plants migrated downwards for at least three years, but that the bottom depth for characeans did not show a measurable change. The shallow turf / low-native communities were affected short term, but recovery was rapid (within weeks). These findings led to the reinstatement of the previous operating levels.

The effects of large-scale changes are difficult to interpret because of a lack of baseline data. The changes that have occurred long term in Lake Monowai were not monitored between the lake's raising in 1926 and the early 1990s, and there are no records of its natural state, so we must rely on various assumptions.

Protecting littoral communities

Kirk and Henriques (1986) have suggested that breaker depth could be used to set minimum operating levels to minimise scouring of weedbeds. Wave estimates are based on fetch, wind direction and wind speed, and must be measured as close as possible to the lake. A key parameter is breaker depth, which is generally assumed to be 1.33 times the significant wave height (average of one-third of highest waves). Based on these calculations, Kirk and Henriques estimated that waves up to 0.5 m high and with periods of up to 4 seconds would be expected on Lake Ohau, producing waves that would break in 0.65 m deep water. To minimise scouring of weedbeds, they suggested that a minimum lake level must be not less than the depth of the shelf-break plus the 0.65 m wave-breaking depth.

Similar calculations were used for Lake Waikaremoana to make recommendations on the minimum lake level that would ensure the community of tall vascular plants in the littoral zone would not be adversely affected by wave activity. In this case, the breaker depth was estimated to be up to 0.63 m. The depth of water required above the macrophyte beds would be expected to be greater in large lakes and where there is a greater fetch (for example, a 1.5 m breaker depth in Lake Coleridge; James et al. 1995).

Quantifying impacts

Quantifying and predicting the potential effects of changing the lake level regime for any given lake is made difficult by the complex and dynamic processes involved. In many lakes the littoral zone makes a significant contribution to lake productivity, and so first we need to know what there is before we can predict what will change. Mapping the extent of shallow water habitats can be carried out by surveying a number of transects using divers, by aerial photography, or by remote sensing. The method used will depend on the size of the lake, the potential significance of any change to values identified for the lake, and the available funding. In smaller mesotrophic lakes diver surveys can be carried out along transects to map the extent of various habitats. If the lake is oligotrophic/mesotrophic, good water clarity may permit aerial photography to be used to quantify different habitats. This method was used, for example, on Lake Otamangakau (Stark and Dedual 1997), where macrophytes were estimated to occupy 93 ha of lake bed. If good bathymetry is available, then digitising the bathymetry over the habitat maps can be used to predict the potential area of different habitats that would be altered under different lake-level regimes.

GIS-based models have considerably advanced our ability to predict the effects of changing lake levels. These models can provide a powerful tool for lake managers to assess the potential effects of different levels on littoral communities and fisheries, and once developed could also be applied to other problems, such as the areas that could be susceptible to exotic weed invasions. An example of the use of GIS models is demonstrated for Lake Taupo in Case study three. This study was funded by Mighty River Power as part of their AEE preparation.

CASE STUDY THREE

Lake Taupo is a large (612 km²), deep (165 m), oligotrophic lake on the central volcanic plateau, New Zealand. The lake is important for its recreational, cultural and spiritual values, and since 1946 the outflow has been controlled before it passes down the Waikato River through eight hydro-electric power stations. Control of the level of Lake Taupo and the artificial hydro lakes for storage purposes downstream is an important aspect of its management.

A GIS-based model was developed to predict the effects of different lake levels on aquatic habitats and communities as part of the preparation of an AEE by Mighty River Power. One of the concerns addressed was the potential for changes to spawning habitat for smelt, which underpin the internationally renowned rainbow trout fishery. Development of the model involved mapping substrates by aerial photography, ground-truthing substrates and habitats, and defining six major habitat categories characterised by different aquatic communities.

A major requirement for this approach is good bathymetry at an appropriate scale. This was achieved by using a high-frequency echo-sounder. Soundings and GPS grid references were loaded into Arc Info, along with habitat maps to determine the area occupied by each habitat category.

Smelt are known to spawn in sandy areas in water depths of 0.5 to 2.5 m. Decreases from the natural maximum lake level of 357.72 m above sea level to 357.39 m above sea level had little effect on the area available, but from the natural median to natural minimum there was a significant decrease in area available. These findings indicated that potentially significant changes in important littoral habitats could occur if water levels were to drop below the natural minimum and were used to make recommendations on lake-operating regimes as part of the consent process.

BOX 7: SUMMARY OF APPROACHES TO ASSESSING IMPACTS

Before any assessments are made, careful consideration needs to be given to the values associated with the resource. These may include:

- intrinsic

- cultural and spiritual

- recreational

- social

- hydro-electric and commercial development.

Once values have been assessed through wide consultation, a description of the existing status of the natural ecosystem is required, along with sensitivities of physical processes and biological communities to lake-level changes.

Details of different approaches are outlined, and include:

- assessing hydrology and lake levels using actual and simulated data to determine natural variation

- assessing wave activity and the potential extent of effects of lake-level change on erosion, longshore transport and the depth of physical disturbance, using models and meteorological data

- assessing lake structures visually (guidelines for construction are provided by the US Corp of Engineers)

- using historical records, which are available for some lakes as an aid to assessing effects

- protection of macrophyte beds (which is generally essential for aquatic productivity) and recommendations for minimum levels based on breaker depth

- quantifying the potential effects on the littoral habitat by mapping the habitats, bathymetry and proposed changes in level. Methods range from simple mapping by divers, to GIS-based models.

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About the Ministry for the Environment

The Ministry for the Environment works with others to identify New Zealand's environmental problems and get action on solutions. Our focus is on the effects people's everyday activities have on the environment, so our work programmes cover both the natural world and the places where people live and work.

We advise the Government on New Zealand's environmental laws, policies, standards and guidelines, monitor how they are working in practice, and take any action needed to improve them. Through reporting on the state of our environment, we help raise community awareness and provide the information needed by decision makers. We also play our part in international action on global environmental issues.

On behalf of the Minister for the Environment, who has duties under various laws, we report on local government performance on environmental matters and on the work of the Environmental Risk Management Authority and the Energy Efficiency and Conservation Authority.

Besides the Environment Act 1986 under which it was set up, the Ministry is responsible for administering the Soil Conservation and Rivers Control Act 1941, the Resource Management Act 1991, the Ozone Layer Protection Act 1996, and the Hazardous Substances and New Organisms Act 1996.

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