Appendix 12: Shallow Lakes

1. Introduction

The Waikato River catchment system is interconnected with shallow lake environments, the backwaters of the hydro lake chain, peat lakes linked via drainage networks and the riverine lakes that lie within the floodplain of the Waikato River. Also unconnected are dune lakes located along the west coast formed in depressions amongst sand dunes. Waterbodies are influenced by, and in turn provide, ecological services to the river that include sediment settling, nutrient removal, flood flow mediation and a nursery or feeding grounds for fisheries. Just as river iwi (tribes) regard the Waikato River as a tupuna (ancestor) and its wai (water) as the lifeblood of that ancestor, the riverine lakes are viewed by river iwi as the 'lungs and kidneys' of their ancestor.

The health and wellbeing of most Waikato shallow lakes is now substantially degraded. Causes of this degradation include:

- High loads of diffuse contaminant inputs of nutrients, sediment and bacteria from run-off and livestock access to the lake.
- Internal regeneration of nutrients from sediment re-suspension (by wind action or pest fish) and/or release of nutrients as a result of low oxygen events at the lakebed.
- High abundance of pest fish (e.g., koi carp and catfish), and/or aquatic weeds (willow, alligator weed, oxygen weed, hornwort).
- Reduced water depth due to drainage and/or reduced flushing due to water control structures and artificial regimes such as the Lower Waikato Flood control scheme.
- Past development of large exotic weed beds that create deoxygenation events and a switch to turbid, nutrient enriched conditions.
- Removal of vegetation filtering potential in the catchment through drainage of marginal wetland vegetation, agricultural development and grazing access.

Analysis of available water quality datasets for 134 New Zealand lakes showed eight of the 18 most nutrient enriched lakes in the country (i.e., hypertrophic) were shallow lakes in the Waikato Region (Hamill and Lew, 2006). Shallow Waikato lakes have many attributes which, if adversely affected, will contribute to their health and poor water quality condition. They include a high proportion of the catchment being in pasture cover, the lakes having a shallow depth (less than 10 metres), a warm Waikato regional climate and low altitude (Sorrell and Unwin, 2007).

Out of 52 lakes in the Waikato River catchment that have been assessed by LakeSPI (a measure of lake condition), nine riverine lakes and 16 peat lakes were decribed as 'non-vegetated' (Edwards et al., 2009). This signals that the survival of widespread submerged plants is no longer possible and, therefore, habitat for native fisheries has been lost. In contrast, the condition of the hydro lakes was reduced by high abundances of exotic water weeds, with implications to lake uses (e.g., interfering with boating and swimming, and blocking hydro-power station intakes) and ecological values in shallow areas.

Abundant populations of pest fish have established widely within the shallow Waikato lakes and while their direct impacts on native fisheries are not well documented, they are known to contribute to degraded water quality (Rowe, 2007) and an absence of submerged vegetation (de Winton et al., 2003).

Now few of the shallow Waikato lakes are suitable for recreational contact, due to insufficient visual clarity (Ministry for the Environment, 1994) or intermittant presence of toxic blue-gree algal blooms (Hamilton and Duggan, 2010), nor are they considered attractive for passive recreation. Some are inaccessible and surrounded by private land. Even though many are also surrounded by associated reserve land, unimpeded access is not always possible.

This appendix considers options for restoring the Waikato shallow lakes. A range of actions are presented, together with their costs and likely effectiveness.

2. Goals for restoration

The restoration of shallow lakes will go some way to meeting the following goals, which address a large number of the values and attributes identified for the Waikato River catchment:

1. Improved water clarity and indicator bacteria to meet bathing standards in fine weather.

2. Improvement of lake nutrient and chlorophyll concentrations meeting meso-trophic condition or better.

3. Improvement of lake aesthetics in terms of marginal plants and water colour and clarity.

4. Expansion of habitat that enhances New Zealand native biodiversity for aquatic and terrestrial plants, and aquatic biota (including waterfowl).

5. Restoration of native macrophytes in lake margins and bottom, which will contribute to restoration and expansion of iinanga (whitebait) habitat.

6. Expansion of the tuna fishery.

The specific goals that could be met by restoration in six representative lakes are summarised in Table 1. In addition to these, all lake margins could be restored to some extent by fencing, planting, afforestation, and allowing flooding to occur.

Table 1: Possible goals for shallow lake restoration in six representative Waikato lakes.

Lake (type)	Tuna	Iinanga	Recreation bacterial standards	Recreation clarity	Aquatic plants	Control or eliminate pest fish
Serpentine (Peat)	-	Yes	Yes	No[1]	Yes	Yes
Ohinewai (Small riverine disconnected)	Yes	Yes	Yes	Yes	Yes	Yes
Otamatearoa (Dune)	No[2]	No	Yes	Yes	Yes	-
Whangapee (Large riverine connected)	Yes	Yes	Yes	Yes	Yes	Yes
Ohakuri (Hydro)	Yes	No	-	-	No	No
Puketiirini (Weavers) (artificial)	Yes	?	Yes	Yes	Yes	Yes

[1] Natural peat staining of the water will limit the improvement that can be achieved.
[2] Can only be achieved by stocking with tuna.

3. Restoration methods

3.1 Overall approach

There are six categories of shallow lakes: peat, small riverine, large riverine, dune, hydro and artificial. An example lake from each category, for which there were data available, was chosen and restoration options scoped. These options could then be extrapolated to other similar lakes (Table 2).

For each lake three restoration options were considered:

Option 1: Maintaining existing water quality (if reasonable) or seeking to improve by standard practices.

Option 2: Applying proven solutions which are highly likely to achieve improvements, with the aim of restoring lakes to a prior water quality condition (e.g., to 1950s water quality for dune lakes as described by Cunningham et al., 1953).

Option 3: Appling novel or theoretical approaches to make substantial and fast acting improvements. This may include extreme actions such as complete retirement of lake catchments to forest.

Table 2: Example lakes for which restoration options were developed.

Lake type	Example	Other lakes of this type
Peat	Serpentine	Rotomaanuka, Ruatuna, Ngaaroto, Mangakaware, Kaituna, Kainui
Small riverine (disconnected[a])	Ohinewai	Rotongaroiti, Rotokawau, Okowhao, Kopuera
Dune	Otamatearoa	Parkinson, Taharoa, Puketi, Rotoroa, Whatihua
Large riverine (connected[a])	Whangapee	Waahi, Waikare, Hakanoa, Rotongaro
Hydro lakes	Ohakuri	Other hydro lakes
Artificial	Puketiirini (Weavers)	Okoko

[a]Connected or disconnected to the river.

3.2 Restoration actions

Narrative tables (Tables 3–8) consider the actions and combinations of actions required for each lake example, and associated costs, but a general description of the potential actions is provided below.

3.2.1 Reduce nutrient and sediment inputs

ACTION 1:

a) Fence and plant riparian buffers around the lake margin[a] and the majority of major tributaries and drains entering the lake.

b) Directly treat larger inflow sources via constructed basins and wetlands.

Establishment of riparian buffers of sufficient extent to intercept and process nutrients, bacterial and sediment loads from the catchment is likely to have major benefits for water quality of the shallow lakes. Expected reductions in loadings are likely to be in the order estimated for five to 15 metre riparian buffers on pasture streams with reduced yields of 15–40 percent nitrogen, 15–65 percent phosphorus, 56–65 percent sediment and 60–75 percent *E. coli* respectively (see Appendix 9: Farms). The scale of restoration activity will vary from a shoreline buffer for lakes without major inflows, to additional fencing and retirement along inflowing drains

[a] With allowance for public access points and corridors for wind passage to mix and oxygenate lakes.

and waterways for larger systems, through to potentially retiring an entire lake catchment where significant and rapid recovery is sought. The required buffer width will need to be determined on a case-by-case basis taking into account local conditions of slope (with wider buffers on steeper slopes), and major inflows may need to be targeted as a priority. Wider buffers are likely to be more effective (e.g., 10–50 metres) and will have greater co-benefits for aesthetics and waterfowl habitat.

Related actions include fencing against stock access, whilst active planting is strongly recommended to minimise weed problems, maximise aesthetic and biodiversity values and for long-term vegetation sustainability. More information on required planting composition, plant grade and density is outlined in Appendix 11: Riparian Aesthetics. Costings for riparian retirement in the catchment are contained in Appendix 9: Farms; however, specific costings for lake buffers have been included here and are based on estimated areas for buffers, land value, and costs of fencing, planting and weed maintenance for about 3 years[b].

Lakes with catchments dominated by native or plantation forest are likely to have better water quality than those dominated by agricultural use (Sorrell et al., 2007); therefore, afforestation of whole catchments is likely to have significant benefits. Economic benefits under the Emissions Trading Scheme may offset lost opportunities from loss of agricultural production, particularly in marginal land areas. However, caution is advised in the case of dune lakes that may be vulnerable to water table changes under exotic forestry and impacts from added fertilisers, common in plantation forestry on sand country.

Additionally, legislation to prevent or restrict intensification, such as a cap on dairy conversions or a review of discharge consents, may be advocated.

Catchment based initiatives on their own may not be sufficient to significantly improve the water quality of receiving lakes. Other solutions might include the construction of basins to allow for processing by wetland systems or infiltration of nutrients (de Winton et al., 2007), or ring drains to divert first flush or nutrient rich inflows. The required scale of these works is subject to site-specific water flows and loadings.

[b] Three years is generally accepted as the length of time that weed control is required for before plants become established (see Appendix 11: Riparian Aesthetics).

ACTION 2:
Prevention of internal regeneration of nutrients by: a) Sediment capping treatments to lock nutrients in the lakebed[c]. b) Drainage and removal of nutrient-rich surface layer.

Information on sediment capping technologies for the hydro lakes is provided in Appendix 21: Toxic Contaminants. As well as the ability to sequester compounds of potential toxicity, capping can substantially reduce internal loading of nutrients, particularly phosphorus (P). Four P-inactivation agents that are currently available are alum, allophane, Phoslock™, and modified zeolite, with required dose rates of these products being highly site-specific according to lake and sediment character (Hickey and Gibbs, 2009). Sediment tests and an initial efficacy trial are therefore recommended before wide-scale treatment. The scale of treatment (whole lake or deeper areas only) and requirement for multiple treatments would also be site-specific and likely to be dependent on initial results.

Internal nutrient loading from wind or pest fish induced re-suspension of bottom sediments and nutrients would be addressed by other actions (see Actions 4 and 6).

A more extreme and costly engineering solution may be to suction dredge, or drain, dry and excavate, the surface sediments where nutrient loads are concentrated. This latter approach has been used in the United States of America (Helsel and Zagar, 2003; Helsel et al., 2003). The logistics are complex and may include the need to pump out water/slurry, bund construction to prevent backfilling, and transport and disposal of spoil. Large impacts on lake values would be expected, at least in the short term, and may include a flush of nutrients released upon re-filling (Stephens et al., 2004). Draw-down could also improve the feasibility of targeting and destroying pest fish (James et al., 2002) as outlined in Action 4.

ACTION 3:
Hydrologic manipulations to: a) Optimise water level regimes[d]. b) Increase flushing flows.

[c] May need to address pest fish and wind/wave re-suspension of sediments in conjunction with this initiative to maintain integrity of the cap.
[d] Weir construction may be accompanied by the need to allow fish passage (see Action 4).

Shallow lakes are vulnerable to water level reductions through excessive drainage, water table losses (e.g., dune lakes), and peat soil drying, decomposition and subsidence (peat lakes). The minimum action undertaken is generally the construction of a weir on lake outlets that helps to set a minimum lake level. However, potential exists to use structures to manipulate lake levels in restoring earlier levels, a prior water table level, or more natural fluctuations/flooding. These additional actions may be necessary for peat lakes where long-term sustainability of lakes is threatened (de Winton et al., 2007). An adaptive management approach is likely to be needed to identify optimal water level regime for specific lakes and identified goals.

For the riverine lakes that are interconnected with the Waikato River, the possibility of routing river water into lakes to increase flushing of nutrients, sediment loads and algal populations has previously been raised. Currently, the water quality of the Waikato River is not good enough to bring substantial benefits to lakes via increased flushing.

Connectivity between the riverine lakes and the lower Waikato River is currently limited by flood schemes. However, the Study team note a conflict between restorative actions (e.g., removal of stop banks and pump stations) and other actions aimed at removing exotic pest species from the lakes, because of their almost certain re-introduction with flood flows (see Action 4).

Removal of dams on the Waikato River would result in the loss of lake habitat and a return to riverine conditions. The Study team would expect water quality to be improved by increased flushing rate, and whilst pest fish and weeds would still be present, weed bed extent would be reduced.

ACTION 4:
Pest fish control by: a) Netting, electrofishing; b) Encouraging a commercial market; or c) Eradication using Rotenone; but d) Allowing for differential fish passage[e].

The aim of reducing and controlling pest fish population size to minimise their impacts on shallow lakes would be an ongoing requirement and cost. In the absence

[e] Would require major barriers for riverine lakes within the river floodplain to prevent pest fish ingress.

of New Zealand information, the Study team would suggest approximate pest fish reductions of 75 percent (Perrow et al., 1997) or to a biomass of less than 150 kilograms ha^{-1} (Hosper and Jagtmen, 1990). Methods for the intensive removal of fish are likely to involve netting or electrofishing. A commercial market for koi carp has briefly operated in the past and remains a possibility, however, commercial fishing relies upon availability of the catch species at an economical level, and so alone it is unlikely to reduce pest population to levels low enough to provide significant benefits to the lakes. There is also a risk that additional populations of pest fish would be intentionally established for economic gain. Alternatively, agencies may fund pest fish harvest, with a commercial market operating for cost recovery. This may require licensing of fishing activities, with remuneration via a bounty scheme or wages.

The alternative of a one-off eradication of pest fish from lake systems is possible in small lakes with limited tributary/drainage networks (Chadderton et al., 2001), but would be more difficult with increasing size and connectivity of lakes. Currently the most likely method is use of the piscicide Rotenone, which is already registered for use in aquatic systems in New Zealand (Hicks et al., 2010). Effective Rotenone use would require sufficient concentrations to penetrate all fish habitats connected to the lake (e.g., drains, tributaries, wetlands). Rotenone is not selective for pest fish alone, but the netting and revival (in a potassium permanganate solution) of affected native fish is theoretically possible. Feasibility of successful Rotenone treatment of lakes would increase if lake levels can be substantially lowered to reduce the treated volume/area (see Action 2). Eradication feasibility must also consider the ongoing risk of reintroduction/reinvasion by pest fish. For example, eradication is not currently considered feasible for large riverine lakes with flood flow connectivity with the Waikato River due to almost certain re-introduction of pests.

Associated with eradication attempts (or intensive fishing) may be the requirement to isolate lakes from connected fish sources and differential fish passage to allow valued native fish (e.g., tuna) to move in and out of lakes, but exclude pest species. Current fish pass solutions can allow access by native fish with climbing abilities, but research on migratory abilities of other native and pest fish would be required to scope and design any differential fish pass for species such as iinanga and mullet.

ACTION 5:
Control or eradicate invasive weeds by: a) Application of herbicides. b) Introduction of grass carp.

Exotic weeds in and around shallow lake environments include trees (e.g., willows), submerged (e.g., egeria, hornwort) and marginal weeds (e.g., alligator weed). The future abundance of some weeds may change with lake management initiatives. In particular, a significant improvement in water quality that creates a habitat with sufficient water transparency for submerged plant growth may well result in exotic weed dominance in the absence of control measures. These submerged weeds may be a future threat to shallow lake usage and biodiversity, and also to water quality. For example, in eutrophic Lake Omapere, large unstable weed beds caused de-oxygenation events that led on to internal nutrient loading events, turbid water and cyanobacterial blooms (Champion and Burns, 2001).

Herbicides are already registered and available for treatment and reduction of biomass of aquatic weeds, and ongoing treatments will progress towards reduced impacts by these species. For emergent and marginal weeds, eradication or near eradication is an appropriate goal of herbicide use. One consideration is appropriate application techniques in sensitive areas (e.g., use of more expensive drill and inject methods for willow instead of aerial spraying where native wetland values are high). Rehabilitation actions in association with control measures (e.g., native plantings after willow control) will make additional control gains.

For submerged weeds, herbicide treatment is proven for amenity purposes to reduce interference around boat ramps, jetties and swimming beaches (Champion and Clayton, 2010). However, the eradication of submerged weeds by herbicide is not a feasible goal in most cases. Nevertheless, research is identifying situations where whole-of-water-body herbicide treatment, or sequential applications, can eradicate some weeds from small lakes. The selective nature of herbicide action against weeds with limited off-target damage to indigenous vegetation means a herbicide approach would be an advantage where native vegetation values are high.

Currently the most certain option for eradication of submerged weeds is by stocking herbivorous grass carp, an exotic fish that is highly unlikely to breed naturally within New Zealand waterways (Rowe and Schipper, 1985). Fish are stocked at a rate depending on the vegetated area of weed present and are capable of removing all submerged vegetation within two to five years. However, in the absence of a proven method to remove them, fish may exert an ongoing grazing pressure in a lake for the rest of their lifespan – up to 20 years. Associated with the use of grass carp may be the need for fish screens or barriers to contain them within a lake.

ACTION 6:
Re-establish native submerged or emergent plants by: a) Active planting of founder colonies. b) Provision of wave barriers.

Once initiatives are undertaken to improve lake water quality and reduce or remove pest species, an opportunity exists to re-introduce a native vegetation that adds cultural values (e.g., reed beds of kuta and raupoo), fish habitat, or provides other ecosystem services such as lakebed stabilisation or wave buffering. Prerequisite to the establishment of native submerged vegetation is sufficient water clarity to allow widespread plant growth, and pest fish control to a level where their disturbance does not prevent plant establishment. In large lakes with a long wind fetch it is also likely that barriers to wave action will need to be constructed to provide protected shallow areas for plants to establish. Active planting of founder colonies of submerged plants will be needed in most cases due to the absence of viable reserves of seed left in the lake sediments. Targeted planting of emergent species will also enhance their re-establishment[f].

ACTION 7:
• Provision of public access.

There is a need to integrate public access needs with other initiatives (e.g., riparian plantings) around the lake edge. These would be built on existing reserves where present, and may require development of paper roads or purchase of land from adjacent landowners. In most cases this would include the minimum of vehicular access and parking, picnic and toilet facilities, and, depending on appropriateness, either a boat ramp or jetty facility (see Appendix 25: Boat ramps). Other public access needs such as boardwalks or tracks and other additional facilities are best considered on a site by site basis via a lake management plan. Another consideration is the associated increased risk of re-introduction of pest species to treated lakes by human activities, which will require public education and local signage.

ACTION 8:
• Monitoring for progress towards goals.

[f] Requires fencing against stock access.

Confirmation of progress towards goals requires ongoing monitoring of the outcomes of initiatives. Ideally lake specific and measurable goals (e.g., reduction in the Trophic Level Index (TLI) measure by one within 10 years), would be laid out in a lake management plan, which integrates catchment level management objectives. Amongst reporting measures that are considered suitable for shallow lakes are the lake TLI (Burns et al., 1999), which indicate nutrient status based on four water quality parameters sampled four to eight times per year, and LakeSPI (Clayton and Edwards, 2006) that indicate ecological condition based on Submerged Plant Indicators. Baseline and future Report Cards for shallow lakes should incorporate one or both of these measures.

4. Benefits/outcomes

Where possible, the benefits of actions are outlined for each example lake in Tables 3–8. Specific and measurable benefits for lakes cannot be identified for each action because significant benefits usually depend upon a chain of actions. Additionally some outcomes are not certain, or are site-specific. For example, restoration of water clarity for re-establishment of widespread native submerged vegetation in Lake Whangapee is likely to depend on the removal of substantial nutrient loads (external and internal), a radical reduction in pest fish, exclusion or control of submerged weeds, and temporary or more sustained reduction in wave action.

Removal of major loadings of nutrients, sediments and bacteria from the catchment are highly likely under restoration options 2 and 3. Flow on benefits for lake water quality (improved clarity and suitability for swimming) will occur, but the timeframe for such outcomes is not so clear. This is because nutrients will have accumulated in the lake sediments over decades and net export or burial of these deposits may take comparable timeframes. Under restoration option 2 benefits would be expected within 30 years. The additional actions under option 3 (e.g., sediment capping and dredging) are likely to not only increase the level of improvement but also to speed recovery to within five to 10 years by removing or capping the nutrient-laden sediments.

Greatest benefit may come from actions in priority areas; for example, addressing condition and impacts from the Whirinaki arm of Lake Ohakurii would have large downstream benefits for the rest of the hydro lake chain.

Co-benefits of actions to restore shallow lake environments include:

- reduced release of toxic substances from hydro lake sediments following sediment capping (see Appendix 21: Toxic contaminants);
- re-establishment of culturally important plant species (e.g., kuta);

- increased habitat for waterfowl, with larger resident populations, in response to increased size of riparian buffers.

5. Risks and probability of success

In New Zealand, lake restoration has never been attempted on the scale required to make significant improvements to the more degraded shallow lakes of the Waikato system. There are significant uncertainties about the outcome of actions, whilst the complexity and level of interacting factors mean a high level of unpredictability in these systems, particularly in the larger lakes where feasibility of undertaking actions alone would be a challenge. In most cases an adaptive management approach will be required with a sequential series of actions, with assessment at each step and reconsideration/adjustment of subsequent steps. Generally, smaller, more isolated lakes are considered most feasible to restore, because pest reinvasion is less likely, fishing activities can be better targeted, and wind/wave mediated impacts on water quality are limited.

One example of the complexity and level of problems can be seen when considering the large riverine lake, Lake Waikare, which would be a much more difficult restoration target than our example lake, Lake Whangapee. Lake Waikare is three times the size of Lake Whangapee and has an open shoreline configuration, lacking the sheltered arms of Lake Whangapee, which creates extensive wind fetch and impacts of wave action on the lakebed and shores. Consequently the lake has high levels of suspended solids that contribute to poor water quality; although, even if all suspended solids were removed, water clarity and light penetration would still be low due to high levels of chlorophyll and humic staining (Reeves et al., 2002). A wave model for the lake suggests that increasing the lake level by one metre would reduce the quantity of sediment re-suspended by waves, but fine clays that are more easily suspended may still drive disproportionately high levels of turbidity. Direct wave action is also a major limitation for the development of marginal and submerged vegetation in the shallow areas of Lake Waikare. The large Matahuru Stream inflow contributed 95 percent of sediment load to Lake Waikare. Options to intercept and treat via wetland filters or silt traps were limited by scale of treatment required and site constraints. Nevertheless, riparian initiatives were recommended for the stream and tributaries to intercept or prevent sediment and nutrient loading to the Matahuru Stream. Natural geothermal inputs to Lake Waikare result in elevated levels of heavy metals in the lakebed (N. Kim, Environment Waikato, pers. comm., 2002), which may be an issue for dredging options and disposal of spoil. It was concluded that the number and scale of problems made it a poor candidate for rehabilitation (Stephens et al., 2004).

Environment Waikato is currently working with local landowners, iwi, community groups and other agencies to improve the health of Lake Waikare. They are also working with landowners in the Matahuru catchment to protect streams flowing into the lake, which will help in reducing the amount of sediment reaching the lake[g].

Some actions are at odds with other possible goals. For example, a suggested aspiration for increased connectivity between water bodies compromises the goal to prevent the introduction/reintroduction of pest fish and weeds. Limiting connectivity to prevent pest ingress also limits the reinstatement or improvement of some fisheries (e.g., iinanga, mullet) due to corresponding barriers to their migration. Other restoration actions involving manipulating lake levels and hydrology would reduce flood control capacity, with implications for adjacent land areas.

There is a high risk of reinfestation by natural, accidental or deliberate introduction of pest fish and weeds to lakes, which may necessitate further rehabilitation efforts in the future. Other risks associated with restoration actions include the possibility of a return to exotic weed dominance if an improved water clarity is achieved in the riverine lakes. Contingency for weed control or eradication should be considered as part of the restoration sequence.

6. Costs and timelines

Narrative tables (Tables 3–8) present the specific actions required for each lake example and their associated costs within the three restoration options. Costings include lake buffer zones of differing extent, but do not include riparian fencing and planting in the catchment (see Appendix 9: Farms). Note that costs associated with riparian fencing and planting in the catchment will vary considerably from lake to lake, with no cost for a dune lake such as Lake Otamatearoa that has no tributary or drain inflows, to a substantial amount for lakes with large catchments such as Lake Whangapee (31,684 hectares). Summary costs for the example lakes over a 30 year restoration period are outlined in Table 9. Within the Waikato River catchment 54 lakes of two hectares or more in size were identified that could be categorised into one of the six shallow lake types. In Table 10 costs based on the example lakes have been extrapolated to the wider group of lakes that might represent priorities for restoration. Costs over a 30 year restoration period were based on scenarios where lake-specific combinations of actions were selected according to feasibility and cost.

No attempt has been made to estimate costs for the possible decommissioning and removal of Ohakurii dam. Such costs would include marginal value (as the cost of generating power elsewhere), the cost of removal of plant and equipment, and impacts on operational costs at downstream power stations (D. Scarlet, Mighty River Power Ltd, pers comm.). Other unknowns are the maintenance cost of fencing and

[g]http://www.ew.govt.nz/environmental-information/Rivers-lakes-and-wetlands/Learn-about-our-lakes/Shallow-lakes-of-the-Waikato-region/Riverine-lakes/Lake-Waikare/

riparian plantings beyond three years, site-specific requirements of dose rate, testing and multiple treatments for sediment capping, and costs for consents and permits (e.g., for herbicide/piscicide application, species collection and translocation, grass carp effects assessment) which will vary widely depending on the required level of detail and/or consultation. Likewise, costs for lake management plans have not been included in this exercise. Potential cost recovery via a commercial market for pest fish is unclear. Another example is containment costs for grass carp (such as barriers at all inlets and outlets), which are likely to be highly site specific.

Table 3: Lake Serpentine: summary of actions, costs and benefits, with an estimation of the certainty of a successful outcome. Operating costs are expressed on a per annum basis, unless indicated otherwise.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
Fencing and planting					
1a. Fence margins for 10 m wide functional buffer and stock exclusion	3 string electric $5/m	Nil	Already fenced		
1b. 10 m planted riparian margin	Native plantings[h] $20,500/ha	Nil	Already planted		
1. Total (OPTION 1)			**Nil**		**Already completed**
2a. Fencing margins for 50 m wide functional buffer and stock exclusion	3 string electric $5/m	4.6 km perimeter[i]	$23,045	Addition to current 20 m planted buffer will see substantial improvement in nutrient interception and filtering.	High
2b. 50 m planted riparian margin	Native plantings $20,500/ha	6.4 ha[j]	$131,200	50 m buffer recommended to protect/contribute to peat dams that ensure lake persistence. Addition to current 20 m planted buffer will see substantial improvement in nutrient interception and filtering. Additional aesthetic values and significant increase in bird habitat.	Moderate to high buffer role in peat protection and accretion is not assured and additional steps may be required long-term – see below.
2c. Land production lost	90% $1,403 per ha per annum, 10% $1,473 per ha per annum[k]	26.9 ha[l]	$37,860 per annum		Low to moderate (multiple owners, dairy and lifestyle).

[h] PB2 grade plants @ 2,500 stems/ha ($5 planted) + maintenance to year three ($8,000/ha).
[i] Estimated 50 m wide margin around lake complex.
[j] Estimated area not currently planted within the 50 m + wetland margins around the lake complex.
[k] Based on values from Appendix 9: Farms. Ninety percent catchment in dairy peat drain $1,403 per ha and 10 percent catchment in lifestyle (dairy poor drain) $1,473 per ha.
[l] 50 m + area = 37.2 ha less WONI database lake area = 10.347 ha.

Table 3 (cont.): Lake Serpentine.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
2. Total (OPTION 2)			**$103,045 + $89,060 operating**		
3a. Fenced margins of entire catchment	Post and batten fences $18/m	5.88 km[m]	$105,840	Significant reduction in indicator bacteria (some residual from waterfowl) and nutrient loadings.	High.
3b. Afforestation of entire catchment	Native plantings $20,500/ha	139.4 ha[n]	$2,857,700	Very significant aesthetic benefits as well as function in reducing nutrient loadings. Very significant contribution to conserving peat and lake persistence. Significantly improved water quality. Creation of significant bird habitat.	High. Water clarity will remain naturally low due to peat.
3c. Land production lost	90% $1,403 per ha per annum, 10% $1,473 per ha per annum[o]	110 ha[p]	$155,100 per annum		Low to moderate (multiple owners, dairy and lifestyle).
3. Total (OPTION 3)			**$1,848,340 + $1,270,300 operating**		

[m] Estimated catchment perimeter.
[n] WONI database catchment area = 160 ha minus WONI database lake area of 10.3 ha minus Wildlands consultants' report 2009 catchment in native vegetation = 8 percent.
[o] Based on values from Appendix 9: Farms. Ninety percent catchment in dairy peat drain $1,403 per ha and 10 percent catchment in lifestyle (dairy poor drain) $1,473/ha.
[p] WONI database catchment area = 160 ha minus WONI database lake area = 10.3 ha minus reserve area ~40 ha.

Table 3 (cont.): Lake Serpentine.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
Access					
4. Public access to lake – entrance, car park, jetty, single toilet and picnic area	$105,000[q] + consent fees + $25,000 maintenance per annum	1	$105,000 + $25,000 maintenance per annum		High.
4. Total (OPTION 2)			**$105,000 + $25,000 operating**		
Monitoring					
5a. Lake monitoring using LakeSPI	$2,100	1	$2,100	Monitor native and exotic submerged vegetation as an indicator of lake health.	High.
5a. Total (OPTION 2)			**$2,100 operating**		
5b. Lake monitoring using LakeSPI and Trophic Lake Index	$2,100 pa + $9,235 pa for four visits	1	$11,235	Monitor native and exotic submerged vegetation as an indicator of lake health plus monitor Trophic Level Index as an indicator of lake health.	High.
5b. Total (OPTION 3)			**$11,235 operating**		

[q] Based on cost estimates from Waipa District Council for similar projects completed by Council.

Table 3 (cont.): Lake Serpentine.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
Farm contaminants					
6. Infiltration filters or ring drain	Backfill and construct filters ($2.5–5k each) or ring drain ($6–7.5k) for major drains	c. 2–4 filters, 1 ring drain (intercepting 5 drains)	$11,000–$27,500	Nutrient loads likely to be further reduced by removing channelised flows to the lake and allows opportunity for infiltration and maximal nutrient processing in the buffer zone where fluctuating water table.	Moderate.
6. Total (OPTION 2)			**$27,500 + 10% operating**		
Pest fish					
7a. i) Pest fish control by intensive netting. Cost may be partially recovered through commercial harvesting (agency driven) of pest fish	~$30,000 per annum [r]	1	$30,000 per annum	Flow on effects for reduced internal nutrient loading, improved water clarity and habitat for submerged plants.	Moderate.
7a. ii) Selective fish pass for tuna, lamprey, iinanga and other galaxiids (whitebait)/pest fish barrier	5 m ramp	1	$50,000 + $10,000 maintenance per annum	Allows upstream fish passage. Tuna passage to a pest fish controlled habitat is likely to afford benefits for the tuna fishery. Upstream passage for smelt, mullet and trout will be blocked but smelt should be able to develop a landlocked population.	High (in association with pest fish control/eradication).
7a. Total (OPTION 2)			**$50,000 +** **$40,000 operating**		

[r] Lake Serpentine Management Action Plan report.

Table 3 (cont.): Lake Serpentine.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
7b. i) Pest fish eradication by piscicide	Low cost of material and application, cost determined by consent process estimated at $100,000	1	$100,000	Significant reduction in internal nutrient loading, improved water clarity and habitat for submerged plants.	Moderate.
7b. ii) Selective fish pass for tuna, lamprey, iinanga and other galaxiids (whitebait)/pest fish barrier	Up to a 5 m ramp	1	$50,000 + $10,000 maintenance per annum	Allows upstream fish passage. Passage to a pest fish controlled habitat is likely to afford benefits for the tuna fishery. Upstream passage for smelt, mullet and trout will be blocked but smelt should be able to develop a landlocked population.	High (in association with pest fish control/eradication).
7b. Total (OPTION 3)			**$150,000 + $10,000 operating**		
Sediment capping					
8. Sediment capping whole lake with modified zeolite (Aqua-P)	$2,400 per tonne Aqua-P + sediment test, calibration, monitoring + consent costs	31 tonnes Aqua-P	$400,000	Little improvement to current water quality except possibly in South Lake.	Moderate – catchment nutrient sources and pest fish need to be reduced in conjunction with sediment capping.
8. Total (OPTION 3)			**$400,000**		

Table 3 (cont.): Lake Serpentine.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
Water level control					
9a. Alterations to weir to raise and reinstate common water level	$200,000[s]	1	$200,000	Reconnection of the three basins and deeper lake depths are likely to confer long-term protection to lakes against drainage/subsidence.	Moderate.
9b. Construction of a bund (1.3 km long, 1.5 m high) and backfilling of outlet drain across lower catchment to preserve peat deposits	$440,000[t] + consent, tip fees, design, landscaping and management costs	1	$440,000 + consent, tip fees, design, landscaping and management costs.	Long-term sustainability of the lakes improved by protection and accretion of peat by raised water table to near ground surface around lakes and immediate downstream peat deposits.	Moderate.
9. Total (OPTION 3)			**$640,000**		

[s] Estimate from Environment Waikato for water level control structures.
[t] Beca Engineering Limited estimate.

Table 4: Lake Ohinewai: summary of actions, costs and benefits, with an estimation of the certainty of a successful outcome. Operating costs are expressed on a per annum basis, unless indicated otherwise.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
Fencing and planting					
1a. Fence 1 m margin for stock exclusion	3 string electric $5/m	1,902 m lake perimeter[u]	Nil, already fenced		
1b. 1 m wide planted riparian margin	Native plantings[v] $20,500/ha	1.9 ha	Nil, already planted		
1c. Land production lost	-	-	-		
1. Total (OPTION 1)			**Nil**		**Already completed.**
2a. Fence margins for 10 m wide functional buffer and stock exclusion	3 string electric $5/m	2.150 km perimeter	$10,750	Reduction in indicator bacteria (some residual from waterfowl) and nutrient loadings.	Moderate to high.
2b. 10 m wide planted riparian margin	Planting $20,500/ha	3.6 ha	$73,800	Significant aesthetic benefits as well as function in reducing nutrient loadings.	Moderate to high.
2c. Land production lost	$1,473 per ha per annum[w]	3.6 ha	$5,300 per annum		
2. Total (OPTION 2)			**$55,750 + $34,100 operating**		
3a. Fencing margins for 50 m + contour wide functional buffer and stock exclusion	3 string electric $5/m	3.7 km perimeter	$18,500	Significant reduction in indicator bacteria and nutrient loadings. Delay in lake water quality likely until residual nutrient load is exported or treated (see 5 below).	Moderate to high.

[u] WONI database value of 1,902 m lake perimeter.
[v] PB2 grade plants @ 2500 stems/ha ($5 planted) + maintenance to year three ($8,000/ha).
[w] Based on catchment in dairy poor drain $1,473 per ha, values from Appendix 9: Farms.

Table 4 (cont.): Lake Ohinewai.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
3b. 50 m + contour and planted riparian margin	Planting $20,500/ha	28.6 ha	$586,300	Significant aesthetic benefits as well as function. Significant reduction in indicator bacteria and nutrient loadings. Creation of significant bird habitat.	Moderate to high.
3c. Land production lost	$1,473 per ha per annum	28.6 ha	$42,130 per annum		
3. Total (OPTION 3)			**$376,000 + $270,930 operating**		
4a. Fenced margins of entire catchment	3 string electric $5/m	11.52 km[x]	$57,600	Very significant reduction in indicator bacteria and nutrient loadings. Delay in lake water quality likely until residual nutrient load is exported or treated (see 5 below).	High.
4b. Afforestation of entire catchment	Planting $20,500/ha	313.8 ha[y]	$6,432,900	Very significant aesthetic benefits as well as function; very significant reduction in indicator bacteria and nutrient loadings. Creation of very significant bird habitat.	
4c. Land production lost	$1,473 per ha per annum	63.30[z]	$93,240 per annum		
4. Total (OPTION 3)			**$3,980,100 + $2,603,640 operating**		

[x] WONI database value of 11,520 m catchment perimeter.
[y] WONI catchment area 3,309,300 m^2 less WONI lake area 170,711 m^2.
[z] Wildlands Consultants' report 2009 is 68.3 ha – lake area of 5 ha.

Table 4 (cont.): Lake Ohinewai.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
Access					
5. Public access to lake – entrance, car park, toilet, picnic area and jetty	$105,000 + $25,000 pa maintenance[aa]	1	$105,000 + $25,000 pa maintenance	Significant access and recreational benefits.	High.
5. Total (OPTION 2)			**$105,000 + $25,000 operating**		
Monitoring					
6a. Lake monitoring using LakeSPI	$2,100 pa	1	$2,100	Monitor native and exotic submerged vegetation as an indicator of lake health.	High.
6a. Total (OPTION 2)			**$2,100 operating**		
6b. Lake monitoring using LakeSPI and Trophic Lake Index	$2,100 pa + $9,235 pa for four visits	1	$11,235	Monitor native and exotic submerged vegetation as an indicator of lake health plus monitor Trophic Level Index as an indicator of lake health.	High.
6b. Total (OPTION 3)			**$11,235 operating**		
Farm contaminants					
7. Infiltration filters	Backfill 2 major drains and construct infiltration filter at c. $4–5 k each[bb]	2 major drains	~$10k + ~$1k maintenance costs	Additional benefits to riparian buffer in intercepting and treating nutrient sources.	Moderate.

[aa] Based on cost estimates from Waikato District Council, Waipa District Council and Beca Engineering Limited.
[bb] Lake Serpentine Management Action Plan report.

Table 4 (cont.): Lake Ohinewai.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
7. Total (OPTION 2)			**$10,000 + $1,000 operating**		
Sediment capping					
8. Sediment capping whole lake with alum followed by modified zeolite (Aqua-P)	$650 per tonne alum; $2,400 per tonne Aqua-P; + sediment test, calibration, monitoring + consent costs	25.6 tonnes alum; 51.2 tonnes Aqua-P	$479,120 + consent costs	Significantly improved water quality and reduced nutrients in water column and lakebed, particularly phosphorus. Alum removes phosphorus from water column. Aqua-P removes phosphorus, arsenic, mercury and some ammonia, and creates a thick cap on lakebed so that sediments are unlikely to become re-suspended.	Moderate – catchment nutrient sources and pest fish need to be reduced, plus selective fish pass in conjunction with sediment capping.
8. Total (OPTION 3)			**$479,120**		
Pest fish					
9a. i) Pest fish control by intensive netting. Cost may be partially recovered through commercial harvesting (agency driven) of pest fish	$100k initial control then $60k per annum [cc]		$100k+ $60k per annum	Flow on effects for reduced internal nutrient loading, improved water clarity and habitat for submerged plants.	Moderate.

[cc] Based on Serpentine Lakes estimate scaled up for Lake Ohinewai.

Table 4 (cont.): Lake Ohinewai.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
9a. ii) Electrofishing	Nil[dd]	Test	Likely to be nil but not ongoing	Flow on effects for reduced internal nutrient loading, improved water clarity and habitat for submerged plants.	Moderate.
9a. iii) Selective fish pass for tuna, lamprey, iinanga and other galaxiids (whitebait)/pest fish barrier	Up to 5 m ramp	1	$50k + $10k maintenance per annum	Allows upstream fish passage. Tuna passage to a pest fish controlled habitat is likely to afford benefits for the tuna fishery. Upstream passage for smelt, mullet and trout will be blocked but smelt should be able to develop a landlocked population.	High.
9a. Total (OPTION 2)			**$50k + $170k operating**		
9b. i) Pest fish eradication by piscicide	Low cost of material and application, cost determined by consent process estimated at $100k		$100k	Significant reduction in internal nutrient loading, improved water clarity and habitat for submerged plants.	Moderate.
9b. ii) Selective fish pass for tuna, lamprey, iinanga and other galaxiids (whitebait)/pest fish barrier	Up to 5 m ramp	1	$50k + $10k maintenance per annum	Allows upstream fish passage. Tuna passage to a pest fish controlled habitat is likely to afford benefits for the tuna fishery. Upstream passage for smelt, mullet and trout will be blocked but smelt should be able to develop a landlocked population.	High.
9b. Total (OPTION 3)			**$150k + $10k operating**		

[dd] Lake Ohinewai identified as possible test lake for pest fish reduction under University of Waikato research.

Table 4 (cont.): Lake Ohinewai.

Action	Costs			Benefit	Certainty of outcome
	Cost item	**Quantity**	**Total cost**		
Aquatic plants					
10. Re-establish founder submerged plant communities	\$22k per 10 m^2 + species translocation permit costs	Either 10m^2 or 10 enclosures	\$22k	Would require improved water quality to attempt. Significant benefits to water quality, aesthetics and fish habitat are likely.	Moderate.
10. Total (OPTION 3)			**\$22k**		

Table 5: Lake Otamatearoa: summary of actions, costs and benefits, with an estimation of the certainty of a successful outcome. Operating costs are expressed on a per annum basis, unless indicated otherwise.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
Fencing and planting					
1a. Fencing margins for stock exclusion	3 string electric $5/m	900 m lake perimeter[ee]	$4,500	Measurable reduction in indicator bacteria (some residual bacteria from waterfowl).[ff] Improved swimmable standard.	High.
1b. 1 m wide planted riparian margin	Native plantings[gg] $20,500/ha	900 m^2	$18,450	Little aesthetic benefit over current condition.	High.
1c. Land production lost	-	-	-		
1. Total (OPTION 1)			**$15,750 + $7,200 operating**		
2a. Fencing margins for 10 m wide functional buffer and stock exclusion	3 string electric $5/m	1.026 km perimeter	$5,130	Significant reduction in indicator bacteria (some residual from waterfowl) and nutrient loadings.	Moderate to high.
2b. 10 m wide planted riparian margin	Planting $20,500/ha	1.13 ha[hh]	$23,165	Significant aesthetic benefits as well as function in reducing nutrient.	Moderate to high.
2a. Land production lost	$323 per ha per annum[ii]	1.13 ha	$365 per annum		
2. Total (OPTION 2)			**$19,255 + $9,405 operating**		

[ee] WONI database value of 845 metre lake perimeter.
[ff] Need for some margins to be maintained as open habitat for rare plants by grazing/mowing/herbicide.
[gg] PB2 grade plants @ 2,500 stems/ha ($5 planted) + maintenance to year three ($8,000/ha).
[hh] Estimated 10 m buffer area = 6 ha less area of lake, WONI database = 4.87 ha.
[ii] Based on catchment in sheep and beef Class 4, $323 per ha; values from Appendix 9: Farms.

Table 5 (cont.): Lake Otamatearoa.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
3a. i) Fencing margins for 50 m functional buffer and stock exclusion	3 string electric $5/m	1.28 km perimeter	$6,420	Significant reduction in indicator bacteria (some residual from waterfowl) and nutrient loadings.	Moderate to high.
3a. ii) 50 m planted riparian margin	Planting $20,500/ha	5.23 ha[jj]	$107,215	Significant aesthetic benefits as well as function in reducing nutrient loadings. Improved water quality. Creation of significant bird habitat.	Moderate to high.
3a. iii) Land production lost	$323 per ha per annum	5.23 ha	$1,690 per annum		
3a. Total (OPTION 3)			**$71,795 + $43,530 operating**		
3b. i) Fenced margins of entire catchment	3 string electric $5/m	3.42 km	$17,100	Significant reduction in indicator bacteria (some residual from waterfowl) and nutrient loadings.	Moderate to high.
3b. ii) Afforestation of entire catchment	Planting $20,500/ha	40.5 ha	$830,250	Very significant aesthetic benefits as well as function in reducing nutrient loadings. Significantly improved water quality. Creation of significant bird habitat.	Moderate to high.
3b. iii) Land production lost	$323 per ha per annum	40.5 ha	$13,080 per annum		
3b. Total (OPTION 3)			**$523,350 + $337,080 operating**		

[jj] Estimated 50 metre buffer area = 10.1 hectares less area of lake, WONI database = 4.87 hectares.

Table 5 (cont.): Lake Otamatearoa.

Action	Costs			Benefit	Certainty of outcome
	Cost item	**Quantity**	**Total cost**		
Weed control					
4a. Herbicide eradication of weed	Endothall product cost of $28 per litre for 800 L[kk] (recommended 3 ppm), applicator costs of $4k per application, compliance costs[ll]	4 ha vegetated	$26,400	Eradication of weed considered likely, but could be increased with repeat applications at lower concentration (higher cost). No/minimal impacts on marginal and native submerged vegetation.	Moderate.
4a. Total (OPTION 2)			**$26,400**		
4b. Stock grass carp for weed eradication	$25 per 25 cm fish, 40 fish per vegetated ha + AEE + $7,000[mm] no containment costs	4 ha vegetated	$11,000	Eradication of weed within 2–5 years, but impacts on submerged and marginal vegetation values will occur until fish can be removed (questionable) or attrition by mortality (15–20 years).	High.
4b. Total (OPTION 3)			**$11,000**		
Access					
5a. Public access to lake – entrance, car park, toilet, picnic area and jetty	$105,000 + $25,000 pa maintenance[nn]	1	$105,000 + $25,000 per annum maintenance	Significant access and recreational benefits.	High.

[kk] WONI database lake area = 4.87 hectares.
[ll] Depending on level of consultation required.
[mm] Depending on level of consultation required.
[nn] Based on cost estimates from Waikato District Council, Waipa District Council and Beca Engineering Limited.

Table 5 (cont.): Lake Otamatearoa.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
5b. Purchase of land for access way	$4,037.50/ha[oo]	0.5 ha	$2,020		Moderate.
5. Total (OPTION 2)			**$185,000 +** **$25,000 operating**		
Monitoring					
6a. Lake monitoring using LakeSPI	$2,100 pa	1	$2,100	Monitor native and exotic submerged vegetation as an indicator of lake health.	High.
6a. Total (OPTION 2)			**$2,100 operating**		
6b. Lake monitoring using LakeSPI and Trophic Lake Index	$2,100 pa + $9,235 pa for four visits	1	$11,235	Monitor native and exotic submerged vegetation as an indicator of lake health plus monitor Trophic Level Index as an indicator of lake health.	High.
6b. Total (OPTION 3)			**$11,235 operating**		

[oo] Based on sheep and beef Class 4, $323 discounted at eight percent over 30 years; values from Appendix 9: Farms.

Table 6: Lake Whangapee: summary of actions, costs and benefits, with an estimation of the certainty of a successful outcome. Operating costs are expressed on a per annum basis, unless indicated otherwise.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
Fencing and planting					
1a. Fencing margins for stock exclusion	3 string electric $5/m	29.5 km lake perimeter[pp]	Nil, required by EW rule	Reduced grazing pressure on turf plant communities. Limited reduction in indicator bacteria. Improved swimmable standard.	High.
1b. 1 m wide planted riparian margin	Native plantings[qq] $20,500/ha	3 ha	$61,500[rr]	Little aesthetic benefit over current condition.	-
1. Total (OPTION 1)			**$37.5k + $24k operating**		
2a. Fencing margins for 10 m wide functional buffer and stock exclusion	3 string electric $5/m	29.6 km perimeter	Nil, required by EW rule	Reduction in indicator bacteria (some residual from waterfowl) and nutrient loadings. Reduced grazing pressure on turf plant communities.	Moderate to high.
2b. 10 m wide planted riparian margin	Planting $20,500/ha [ss]	29.5 ha	$604,750[tt]	Significant aesthetic benefits as well as function in reducing nutrient.	Moderate to high.
2c. Land production lost	$1,467 per ha per annum[uu]	29.5 ha	$43,280 per annum		
2. Total (OPTION 2)			**$368,750 + $427,280 operating**		

[pp] GIS (geographical information system) value of 29,544 m lake perimeter.
[qq] PB2 grade plants @ 2,500 stems/ha ($5 planted) + maintenance to year three ($8,000/ha).
[rr] Includes three years of maintenance costs following planting.
[ss] PB2 grade plants @ 2,500 stems/ha ($5 planted) + maintenance to year three ($8,000/ha).
[tt] Includes three years of maintenance costs following planting.
[uu] Based on dairy free drain $1,467 per ha; values from Appendix 9: Farms.

Table 6 (cont.): Lake Whangapee.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
3a. Fencing margins for 50 m + contour wide functional buffer and stock exclusion	3 string electric $5/m	124.1 km perimeter	$620,500	Significant reduction in indicator bacteria (some residual from waterfowl) and nutrient loadings. Reduced grazing pressure on turf plant communities.	Moderate to high.
3b. 50 + wetland and planted riparian margin	Planting $20,500/ha	1,730 ha	$35,465,000	Significant aesthetic benefits as well as function in reducing nutrient loadings. Improved water quality. Creation of significant bird habitat. Reduced grazing pressure on turf plant communities.	Moderate to high.
3c. Land production lost	$1,467 per ha per annum[vv]	1,730 ha	$2,537,910 per annum		
3. Total (OPTION 3)			**$22,245,500 + $16,377,910 operating**		
4a. Fencing catchment margins	Post and batten fences $18/m	135 km catchment perimeter	$2,430,000	Extreme reduction in indicator bacteria (some residual from waterfowl) and nutrient loadings.	High.
4b. Planting of catchment	Planting $20,500/ha	28,105 ha[ww]	$576,152,500	Very significant aesthetic benefits as well as function in reducing nutrient loadings. Significantly improved water quality. Creation of significant bird habitat. Reduced grazing pressure on turf plant communities.	High.

[vv] Based on dairy free drain $1,467 per ha; values from Appendix 9: Farms.
[ww] GIS total catchment area 31,721.4 ha less Wildlands consultants' report 2009 eight percent catchment in native vegetation; less WONI database lake area 1,078.62 ha.

Table 6 (cont.): Lake Whangapee.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
4c. Land production lost	90% of area $180 per ha per annum, 10% $1,467 per ha per annum[xx]	29,295 ha[yy]	$9,043,205 per annum		
4. Total (OPTION 3)			**$353,743,350 + $233,882,355 operating**		
Access					
5. Public access to lake – entrance, car park, toilet, picnic area and boat ramp	$505,000 + $25,000 per annum maintenance[zz]	1	$505,000 + $25,000 per annum	Significant access and recreational benefits.	
5. Total (OPTION 2)			**$505,000 + $25,000 operating**		
Monitoring					
6a. Lake monitoring using LakeSPI	$2,100 per annum	1	$2,100 per annum	Monitor native and exotic submerged vegetation as an indicator of lake health.	High.
6a. Total (OPTION 2)			**$2,100 operating**		

[xx] Based on 90 percent catchment in sheep and beef Class 3, $180 per ha, 10 percent catchment in dairy free drain $1,467 per ha; values from Appendix 9: Farms.
[yy] GIS total catchment area 31,721.4 ha less 1,348.3 ha designated DOC reserve, Waikato District Council proposed plan 2009; less WONI database lake area 1,078.62 ha.
[zz] Based on cost estimates from Waikato District Council, Waipa District Council and Beca Engineering Limited.

Table 6 (cont.): Lake Whangapee.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
6b. Lake monitoring using LakeSPI and Trophic Lake Index	$2,100 per annum + $9,235 per annum for 4 visits	1	$11,235 per annum	Monitor native and exotic submerged vegetation as an indicator of lake health plus monitor Trophic Level Index as an indicator of lake health.	High.
6b. Total (OPTION 3)			**$11,235 operating**		
Willow control					
7a. i) Willow treatment aerial spraying followed by spot spraying (30 percent of area)	$600/ha aerial spraying; $1,200/ha spot spray[aaa] + 10% maintenance costs + consent costs	1,133 ha[bbb]	$1,087,680 + 108,770 maintenance costs + consent costs	Significant aesthetic benefits as well as function in removal of a pest plant replaced by native wetland vegetation. Some non-target spray damage to native vegetation.	Moderate to high. Crack willow eradicated; grey willow spreads via seed so needs ongoing control.
7a. ii) Replant treated willow area with flax wetland and kahikatea forest	Planting $20,500/ha	1,133 ha	$23,226,500	Significant aesthetic benefits. Creation of significant bird habitat. Potential creation of harakeke resource for cultural harvest.	Moderate to high.
7a. Total (OPTION 2)			**$15,250,180 + $9,172,770 operating**		

[aaa] Estimated costs from Waikato Conservancy Office, Department of Conservation: $600/ha boom spray entire area; $1,200/ha spot spraying.
[bbb] Estimated from aerial photographs area = 1,133 ha plus 50 percent repeat spray.

Table 6 (cont.): Lake Whangapee.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
7b. i) Willow treatment aerial spraying followed by spot spraying (30 percent of area) and drill and inject (30 percent of area)[ccc]	$600/ha aerial spraying; $1,200/ha spot spray[ddd]; $25,000/ha drill and inject herbicide[eee] + 10% maintenance costs + consent costs	1,133 ha	$9,585,180 + $958,520 maintenance costs + consent costs	Significant aesthetic benefits as well as function in removal of a pest plant replaced by native wetland vegetation. Little non-target spray damage to native vegetation.	Moderate to high. Crack willow eradicated; grey willow spreads via seed so likely to need ongoing control.
7b. ii) Replant treated willow area with flax wetland and kahikatea forest	Planting $20,500/ha	1,133 ha	$23,226,500	Significant aesthetic benefits. Creation of significant bird habitat. Potential creation of harakeke resource for cultural harvest.	Moderate to high.
7b. iii) Continue weed control of replanted willow area for a further 10 years	$700/ha	1,133 ha	$793,100	Significant aesthetic benefits. Creation of significant bird habitat. Potential creation of harakeke resource for cultural harvest.	Moderate to high.
7b. Total (OPTION 3)			**$23,747,680 + $10,815,620 operating**		

[ccc] Drill and inject can be used in sensitive areas where aerial spraying is not an option.
[ddd] Estimated costs from Waikato Conservancy Office, Department of Conservation: $600/ha boom spray entire area; $1,200/ha spot spraying 30 percent of area.
[eee] Cost estimates based on Waitakere City Council willow control drill and inject 2009/2010 to follow up 30 percent of area.

Table 6 (cont.): Lake Whangapee.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
Farm contaminants					
8a. Constructed wetlands at lake inflows with infiltration filter[fff]	$250,000/ha[ggg] + $495/ha maintenance[hhh]	4 filters over 3.5 ha	$1,000,000[iii] + $1,733 maintenance per annum	Removal of 80% sediments, 60% nitrogen and phosphorus, removal of organic forms of nitrogen and phosphorus, greater reduction of suspended sediments and *E. coli*.[jjj] Removes channelised flows to the lake and allows nutrient processing in the buffer zone.	Low to moderate.
8a. Purchase of land for constructed wetlands at lake inflows with infiltration filter	$18,337.50/ha [kkk]	3.5 ha	$64,181		Low to moderate.
8a. Total (OPTION 2)			**$1,064,181 + $1,733 operating**		
8b. Constructed wetlands at lake inflows with infiltration filter[lll]	ii) $250,000/ha[mmm] + $495/ha maintenance[nnn]	7 filters over 6 ha	$1,750,000[ooo] + $2,970 maintenance pa	Removal of 80% sediments, 60% N and P, removal of organic forms of nitrogen and phosphorus, greater reduction of suspended sediments and *E. coli*.[ppp] Removes channelised flows to the lake and allows nutrient processing in the buffer zone.	Moderate.

[fff] Maintenance costs and consent costs additional.
[ggg] Based on indicative costs for Lake Mangahia; Bodmin et al., (2008). Lake Mangahia management recommendations for lake level, marginal vegetation and nutrient removal. Client report for Environment Waikato.
[hhh] Costs from McKergow et al., (2007). Stocktake of diffuse pollution attenuation tools for New Zealand pastoral farming systems. Constructed wetland maintenance = $15/ha pa. Woodchip filter $4,800/ha * 6 ha lasts for 10 years then replace.
[iii] Information on nutrient levels and drainage flows are required to calculate infiltration filter size plus consent costs.
[jjj] McKergow et al., (2007). Stocktake of diffuse pollution attenuation tools for New Zealand pastoral farming systems.
[kkk] Based on dairy free drain $1,467 per ha discounted at eight percent over 30 years; values from Appendix 9: Farms.
[lll] Consent costs additional.
[mmm] Based on indicative costs for Lake Mangahia; Bodmin et al., (2008). Lake Mangahia management recommendations for lake level, marginal vegetation and nutrient removal.
[nnn] Costs from McKergow et al., (2007). Stocktake of diffuse pollution attenuation tools for New Zealand pastoral farming systems. Constructed wetland maintenance = $15/ha pa. Woodchip filter $4,800/ha * six ha lasts for 10 years then replace.
[ooo] Information on nutrient levels and drainage flows are required to calculate infiltration filter size plus consent costs.
[ppp] McKergow et al., (2007). Stocktake of diffuse pollution attenuation tools for New Zealand pastoral farming systems.

Table 6 (cont.): Lake Whangapee.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
8b. Purchase of land for constructed wetlands at lake inflows with infiltration filter	$18,337.50/ha	6 ha	$110,025		Low to moderate.
8b. Total (OPTION 3)			**$1,860,025 + $2,970 operating**		
8c. Constructed wetlands at lake inflows[qqq]	$7,500/ha construction + $180/ha[rrr] land production lost + $15/ha maintenance [sss]	3% of catchment area = 921 ha[ttt]	$6,904,800 + $165,780 per annum lost production + $13,815 per annum maintenance	Removal of 80 percent sediments, 60 percent nitrogen and phosphorus, and ~90 percent *E. coli*[uuu],	Moderate.
8c. Total (OPTION 3)			**$6,904,800 + $179,595 operating**		

[qqq] Consent costs additional.
[rrr] Based on sheep and beef Class 3, $180 per ha; values from Appendix 9: Farms.
[sss] McKergow et al., (2007). Stocktake of diffuse pollution attenuation tools for New Zealand pastoral farming systems. Constructed wetland maintenance $15/ha pa.
[ttt] Based on indicative areas from McKergow et al., (2007). Stocktake of diffuse pollution attenuation tools for New Zealand pastoral farming systems.
[uuu] McKergow et al., (2007). Stocktake of diffuse pollution attenuation tools for New Zealand pastoral farming systems.

Table 6 (cont.): Lake Whangapee.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
Sediment capping and removal					
9a. Sediment capping whole lake with alum followed by modified zeolite (Aqua-P)	$2,400 per tonne Aqua-P; + sediment test, calibration, monitoring + consent costs	3,237 tonnes Aqua-P	$10,217,560 + costs for consents, management and monitoring	Reduce nutrients in water column and lakebed, particularly phosphorus. Aqua-P removes phosphorus, arsenic, mercury and some ammonia, and creates a thick cap on lakebed so that sediments are unlikely to become re-suspended.	Moderate. Catchment nutrient sources and pest fish need to be reduced in conjunction with sediment capping.
9a. Total (OPTION 3)			**$10,217,560**		
9b. Drain, dig out sediment, dry out. Possibly use for wave barrier?	$5,600,000 to $9,700,000[vvv]	1	$5,600,000 to $9,700,000 dependent on sediment disposal	Reduce nutrients and suspended sediment in lake water to improve water clarity and habitat for submerged plants. Option to reduce pest fish and aquatic weed whilst water levels lowered.	Moderate. Catchment nutrient sources and pest fish need to be reduced in conjunction with sediment removal.

[vvv] Beca Engineering Limited estimate.

Table 6 (cont.): Lake Whangapee.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
9b. Total (OPTION 3)			**$9,700,000**		
Pest fish					
10a. Pest fish control by intensive netting. Cost may be partially recovered through commercial harvesting (agency driven) of pest fish	$50,000 equipment + $200,000 per annum [www]	1	$50,000 + $200,000 per annum	Decrease grazing and disturbance pressure on important native turf plant communities.	Low to moderate – risk of reinvasion from tributaries and Waikato River when flooding.
10a. Total (OPTION 2)			**$50,000 + $200,000 operating**		
10b. Pest fish control treat lake and tributaries with piscicide followed by intensive netting. Cost may be partially offset by commercial harvesting of pest fish	Estimated at $1,000k[xxx] treat lake + $50k equipment + $200k per annum	1,079 ha full lake + tributaries	$1,050,000 + $200,000 per annum	Significant decrease in grazing and disturbance pressure on important native turf plant communities, although ongoing control required to keep pest fish numbers down.	Low.[yyy]
10b. Total (OPTION 3)			**$1,050,000 + $200,000 operating**		

[www] Based on Serpentine Lakes estimate scaled up for Lake Whangapee.
[xxx] Based on Lake Ohinewai estimates scaled up for Lake Whangapee.
[yyy] Pest fish re-introduced when Waikato River floods; difficult to kill all pest fish in tributaries; fish re-introduced from human activity.

Table 6 (cont.): Lake Whangapee.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
Water level control					
11a. Bund along Glen Murray Rangiriri Rd with gates and fish pass	$3,000,000[zzz]	Bund 5 m[aaaa] high and ~150 m long	$3,000k + $300k maintenance + consents + design, tip fees, landscaping and management costs	Allow greater water level fluctuations similar to historical levels, larger habitat area for fish, wetlands and lake margin vegetation. May improve water clarity.	Moderate.
11. Total (OPTION 3)			**$3,000k + $300k operating**		
Wave control					
12a. Wave barriers across arm entrances of lake using manuka brush barriers	$20,000	1	$20,000 + $100,000 maintenance	Protect re-establishing submerged plants, reduce turbidity of water, improve water clarity.	Low to moderate – will aid water within arms but little effect on main lake body.

[zzz] Estimate based on gates and pass at Lake Waikare plus bund cost from Beca Engineering Limited.
[aaaa] Based on Waikato River fluctuations of 4 m from the Rangiriri flow gauge, Environment Waikato website.

Table 6 (cont.): Lake Whangapee.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
12a. Total (OPTION 2)			**$20,000 + $100,000 operating**		
12b. Wave barriers (causeway type) across arm entrances of lake (if sediment is suitable)	$4,182,060[bbbb] + ~10% maintenance	3–4	$16,728,240 + $1,672,825 operating	Protect re-establishing submerged plants, reduce turbidity of water, improve water clarity.	Low to moderate – will aid water within arms but little effect on main lake body.
12c. Replant emergent plants along lake shallows	$33,900 per ha + species translocation permit costs[cccc]	2.1 ha[dddd]	$42,360 + $28,560 operating	Co-benefits to water quality, aesthetics and fish habitat are likely. Act as shelter belts of founder populations of submerged plants.	Moderate – would require improved water quality and pest fish control to attempt.

[bbbb] Based on cost estimates for Lake Waikare by Beca Engineering Limited.
[cccc] Estimated costs root trainer 10,000 plants/ha ($20,300 planted) + maintenance to year three ($13,600/ha) from Wildlands Consultants Limited. These estimates exclude management costs, plant delivery costs, travel and expenses.
[dddd] 10.42 km shoreline and two-metre wide plantings.

Table 6 (cont.): Lake Whangapee.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
12d. Re-establish founder submerged plant communities	$22,000 per 10 m^2 + species translocation permit costs[eeee]	40 m^2	$88k	Co-benefits to water quality, improved water clarity, aesthetics and fish habitat are likely.	Moderate – would require improved water quality and pest fish control to attempt.
12b–d. Total (OPTION 3)			**$16,858,600 + $1,701,385 operating**		
Weed control					
13a. Weed control of hornwort and egeria using herbicide (diquat)	$1,600/ha for diquat product and application + compliance costs	Treat 30% of lake, 324 ha[ffff] + annual control 10% of lake 108 ha[gggg]	$518,400[hhhh] + annual control $172,640	Reduced interference with recreational activities and access. Control of weed considered likely, but could be increased with repeat applications at lower concentration (higher cost), minimal impacts on marginal and native submerged vegetation.	Moderate[iiii].

[eeee] Based on Lake Ohinewai cost estimates.
[ffff] Lake area 1,079 ha from WONI database.
[gggg] Based on current practice in hydro lakes.

[hhhh] Based on one full treatment.
[iiii] If actions improve water clarity, aquatic weeds will flourish and require control (depends on weed extent).

Table 6 (cont.): Lake Whangapee.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
13a. Total (OPTION 2)			**$518,400 + $172,640 operating**		
13b. Stock grass carp for weed control	$25 per 25 cm fish, 40 fish per vegetated ha, + AEE + costs for compliance and containment	Weed bed estimate 80% of lake, 864 ha	$864,000	Eradication of weed within 2–5 years, but reinvasion will occur when the Waikato River floods. Grass carp will impact on marginal vegetation values until fish can be removed (questionable) or attrition by mortality (15–20 years).	Low[jjjj].
13b, Total (OPTION 3)			**$864,000**		

[jjjj] If actions improve water clarity, aquatic weeds will flourish and require control. Re-establishment risk from Waikato River, tributaries and human activity such as boats.

Table 7: Lake Ohakurii: summary of actions, costs and benefits, with an estimation of the certainty of a successful outcome. Operating costs are expressed on a per annum basis, unless indicated otherwise.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
Fencing and planting					
1a. Fencing margins for stock exclusion in Whirinaki Arm	3 string electric $5/m	14.15 km lake perimeter[kkkk]	$70,750	Measurable reduction in indicator bacteria (some residual from waterfowl).	High.
1b. 1 m wide planted riparian margin in Whirinaki Arm	Native plantings[llll] $20,500/ha	1.4 ha	$28,700	Little aesthetic benefit over current condition.	High.
1. Total (OPTION 1)			**$88,250 +$11,200 operating**		
2a. Fencing margins for 10 m wide functional buffer and stock exclusion main lake	3 string electric $5/m	25 km perimeter[mmmmm]	Covered in Appendix 9: Farms	Reduction in indicator bacteria (some residual from waterfowl) and nutrient loadings.	Moderate to high.
2b. 10 m wide planted riparian margin on main lake (5 m planting)	Planting $20,500/ha	25 ha * 0.5	$256,250	Significant aesthetic benefits as well as function in reducing nutrient.	Moderate to high.
2c. Land production lost on main lake (5 m covered in Appendix 9: Farms)	80% $1,473 per ha per annum, 20% $180/ha/annum[nnnn]	25 ha * 0.5	$15,180 per annum		
2. Total (OPTION 2)			**$156,250 + $15,280 operating**		

[kkkk] Estimated perimeter of Whirinaki Arm 14,150 m.
[llll] PB2 grade plants @ 2,500 stems/ha ($5 planted) + maintenance to year three ($8,000/ha).
[mmmmm] Estimated perimeter of Lake Ohakurii excluding Whirinaki Arm 25,117 m.
[nnnn] Based on 80 percent catchment in dairy poor drain $1,473 per ha, 20 percent in sheep and beef Class 3, or forestry $180 per ha; values from Appendix 9: Farms.

Table 7 (cont.): Lake Ohakurii.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
3a. Fencing margins for 50 m + contour wide functional buffer and stock exclusion of main lake	3 string electric $5/m	33 km catchment perimeter [oooo]	$164,900	Significant reduction in indicator bacteria (some residual from waterfowl) and nutrient loadings.	High.
3b. 50 m + wetland and planted riparian margin of main lake (5 m covered in Appendix 9: Farms)	Planting $20,500/ha	144 ha[pppp]	$2,949,950	Very significant aesthetic benefits as well as function in reducing nutrient loadings. Significantly improved water quality. Creation of significant bird habitat.	High.
3c. Land production lost on main lake (5 m covered in Appendix 9: Farms)	$180 per ha per annum[qqqq]	144 ha	$25,900 per annum	Avoid increase in sediment and nutrients at time of forestry harvest.	Moderate.
3. Total (OPTION 3)			**$1,963,650 + $1,177,100 operating**		
4a. Fencing margins for 50 m + contour wide functional buffer and stock exclusion in Whirinaki Arm	3 string electric $5/m	14 km perimeter	$70,000	Significant reduction in indicator bacteria (some residual from waterfowl) and nutrient loadings. Reduced grazing pressure on turf plant communities.	Moderate to high.
4b. 50 m + wetland and planted riparian margin in Whirinaki Arm	Planting $20,500/ha	61.1 ha[rrrr]	$1,252,550	Significant aesthetic benefits as well as function in reducing nutrient loadings. Improved water quality. Creation of significant bird habitat. Reduced grazing pressure on turf plant communities.	Moderate to high.

[oooo] Estimated 50 m perimeter of Lake Ohakuriii excluding Whirinaki Arm 45,540 m less fencing of 5 m buffer covered in Appendix 9: Farms 12,560 m.
[pppp] Estimated 50 m + buffer for Lake Ohakuriii excluding Whirinaki Arm 1,096.4 ha less WONI database lake area 939.976 ha less 5 m planted buffer covered in Appendix 9: Farms 12.5 ha.
[qqqq] Based on Appendix 9: Farms value for sheep and beef Class 3, land and forestry estimated at similar land value $180 per ha.
[rrrr] Estimated area 50 m + buffer = 151 ha less lake area for Whirinaki Arm = 89.9 ha.

Table 7 (cont.): Lake Ohakurii.

Action	Costs			Benefit	Certainty of outcome
	Cost item	**Quantity**	**Total cost**		
4c. Land production lost in Whirinaki Arm	80% $1,473 per ha per annum, 20% $180/ha/annum	61.1 ha	$74,200 per annum		
4. Total (OPTION 3)			**$833,750 + $563,000 operating**		
5a. Fencing catchment margins in Whirinaki Arm	Post and batten fences $18/m	86.4 km catchment perimeter [ssss]	$1,555,200	Significant reduction in indicator bacteria (some residual from waterfowl) and nutrient loadings.	High.
5b. Planting of catchment in Whirinaki Arm	Planting $20,500/ha	16,372 ha[tttt]	$335,626,000	Very significant aesthetic benefits as well as function in reducing nutrient loadings. Significantly improved water quality. Creation of significant bird habitat. Reduced grazing pressure on turf plant communities.	High.
5c. Land production lost in Whirinaki Arm	80% $1,473 per ha per annum, 20% $180 per ha per annum	16,372 ha	$19,882,160 per annum		
5. Total (OPTION 3)			**$206,205,200 + $150,858,160 operating**		

[ssss] GIS Whirinaki Arm catchment perimeter = 86.4 km.
[tttt] GIS Whirinaki catchment area 16,461 ha less lake area for Whirinaki Arm = 89 ha.

Table 7 (cont.): Lake Ohakurii.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
Access					
6. Public access to lake – entrance, car park, toilet, picnic area and boat ramp	Completed		$25k pa maintenance	Already completed.	-
6. Total (OPTION 2)			**Nil**	Already completed.	
Monitoring					
7a. Lake monitoring using LakeSPI	$2,100 pa	1	$2,100	Monitor native and exotic submerged vegetation as an indicator of lake health.	High.
7a. Total (OPTION 2)			**$2.1k operating**		
7b. Lake monitoring using LakeSPI and Trophic Lake Index	$2,100 pa + $9,235 pa for four visits	1	$11,235	Monitor native and exotic submerged vegetation as an indicator of lake health plus monitor Trophic Level Index as an indicator of lake health.	High.
7b. Total (OPTION 3)			**$11,235 operating**		

Table 7 (cont.): Lake Ohakurii.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
Farm contaminants					
8. Constructed wetlands at lake inflows in Whirinaki Arm	$7.5k/ha construction + $1,473/ha pa lost land production[uuuu] + $15/ha maintenance [vvvv]	3%[wwww] of catchment area = 491 ha	$3,682,500 + $727,660 pa land production + $7,410 pa maintenance	Removal of 80% sediments, 60% nitrogen and phosphorus, and ~90% *E. coli*[xxxx]	Moderate.
Farm contaminants					
8. Constructed wetlands at lake inflows in Whirinaki Arm	$7.5k/ha construction + $1,473/ha pa lost land production[yyyy] + $15/ha maintenance [zzzz]	3%[aaaaa] of catchment area = 491 ha	$3,682,500 + $727,660 pa land production + $7,410 pa maintenance	Removal of 80% sediments, 60% nitrogen and phosphorus, and ~90% *E. coli*[bbbbb]	Moderate.
8. Total (OPTION 2)			**$3,682,500 + $735,070 operating**		

[uuuu] Based on Appendix 9: Farms, value for dairy poor drain value $1,473 per ha.
[vvvv] McKergow et al., (2007). Stocktake of diffuse pollution attenuation tools for New Zealand pastoral farming systems. Constructed wetland maintenance $15/ha pa.
[wwww] Three percent based on McKergow et al., (2007). Stocktake of diffuse pollution attenuation tools for New Zealand pastoral farming systems. GIS Whirinaki catchment area 16,461 ha = 494 ha.
[xxxx] McKergow et al., (2007). Stocktake of diffuse pollution attenuation tools for New Zealand pastoral farming systems.
[yyyy] Based on Appendix 9: Farms, value for dairy poor drain value $1,473 per ha.
[zzzz] McKergow et al., (2007). Stocktake of diffuse pollution attenuation tools for New Zealand pastoral farming systems. Constructed wetland maintenance $15/ha pa.
[aaaaa] Three percent based on McKergow et al., (2007). Stocktake of diffuse pollution attenuation tools for New Zealand pastoral farming systems. GIS Whirinaki catchment area 16,461 ha = 494 ha.
[bbbbb] McKergow et al., (2007). Stocktake of diffuse pollution attenuation tools for New Zealand pastoral farming systems.

Table 7 (cont.): Lake Ohakurii.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
Sediment capping					
9a. Sediment capping Whirinaki Arm with alum followed by modified zeolite (Aqua-P)	$650 per tonne alum; $2,400 per tonne Aqua-P; + management + consent costs	135 tonnes alum; 270 tonnes Aqua-P	$1,200,700 + costs for consents, management and monitoring	Reduce nutrients in water column and lakebed, particularly phosphorus. Aqua-P removes phosphorus, arsenic, mercury and some ammonia, and creates a thick cap on lakebed so that sediments are unlikely to become re-suspended.	Moderate.[ccccc]
9a. Total (OPTION 3)			**$1,200,700**		
9b. Sediment capping main lake body with alum followed by modified zeolite (Aqua-P)	$650 per tonne alum; $2,400 per tonne Aqua-P; + management + consent costs	1,410 tonnes alum; 2,820 tonnes Aqua-P	$9,623,050 + costs for consents, management and monitoring	Reduce nutrients in water column and lakebed, particularly phosphorus. Aqua-P removes phosphorus, arsenic, mercury and some ammonia, and creates a thick cap on lakebed so that sediments are unlikely to become re-suspended.	Moderate.[ddddd]
9b. Total (OPTION 3)			**$9,623,050**		
Weed control					
10. Whirinaki Arm weed control using herbicide: endothall for hornwort, diquat for egeria (one full treatment + follow up one third the area)	$5,600/ha[eeeee] for endothall + applicator costs + compliance costs; $1,600/ha for diquat product and application	Weed bed estimate[fffff] 25% of lake for hornwort (62.5 ha) and egeria (62.5 ha)	$585,000 + $40,000 per annum	Reduced interference with recreational activities and access. No/minimal impacts on marginal and native submerged vegetation.	High.

[ccccc] Catchment nutrient sources and pest fish need to be reduced in conjunction with sediment capping.
[ddddd] Catchment nutrient sources and pest fish need to be reduced in conjunction with sediment capping.
[eeeee] Based on the rates used at Lake Otamatearoa.
[fffff] Wells et al., (2000). Mighty River Power aquatic weeds: issues and options.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
10. Total (OPTION 2)			**$585,000 + $40,000 operating**		
11. Weed control using herbicide: endothall for hornwort, diquat for egeria (one full treatment + follow up half the area)	$5,600/ha[ggggg] for endothall + applicator costs + compliance costs; $1,600/ha for diquat product and application	Weed bed estimate[hhhhh] 25% of lake for hornwort (235 ha); 10% lake for egeria (94 ha)	$2,199,600 + $150,400 per annum	Reduced interference with recreational activities and access. No/minimal impacts on marginal and native submerged vegetation.	High.
11. Total (OPTION 2)			**$2,199,600 + $150,400 operating**		
Dam removal					
12. Remove dam, lake reverts to river with flushing flows	$ lost power generation + dam decommission costs	1	$ lost power generation + dam decommission costs	Aquatic weeds largely removed. Habitat changes from lake to river environment. Changes to recreational activities. Disruption of entire ecosystem with reduced water clarity for many years.	Low.
12. Total (OPTION 3)			**$ Extensive**		

[ggggg] Based on the rates used at Lake Otamatearoa.
[hhhhh] Wells, R., Clayton, J., Schwarz, A., Hawes, I., Davies-Colley, R. (2000). Mighty River Power aquatic weeds: issues and options.

Table 8: Lake Puketiirini (Weavers): summary of actions, costs and benefits, with an estimation of the certainty of a successful outcome. Operating costs are expressed on a per annum basis, unless indicated otherwise.

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
Fencing and planting					
1a. 10 m wide planted riparian margin stabilisation and aesthetics	Native plantings[iiiii] $20,500/h[a]	2.8 ha	$57,400	Very significant aesthetic benefits. Maintain or improve water quality. Creation of significant bird habitat.	High.
1b. Land production lost	$180 per ha per annum[jjjjj]	2.8 ha	$500 per annum	Very significant aesthetic benefits. Maintain or improve water quality. Creation of significant bird habitat.	High.
1. Total (OPTION 2)			**$35,000 + $22,900 operating**		
2a. Extend plantings on mine tailings for stabilisation and aesthetics	Native plantings $20,500/ha	70 ha[kkkkk]	$1,435,000	Very significant aesthetic benefits. Maintain or improve water quality. Creation of significant bird habitat.	High.
2b. Land production lost	$180 per ha per annum	70 ha	$12,600 per annum	Very significant aesthetic benefits. Maintain or improve water quality. Creation of significant bird habitat.	High.
2. Total (OPTION 3)			**$875,000 + $572,600 operating**		

[iiiii] PB2 grade plants @ 2,500 stems/ha ($5 planted) + maintenance to year 3 ($8,000/ha).
[jjjjj] Based on catchment in sheep and beef Class 3, $180 per ha; values from Appendix 9: Farms.
[kkkkk] Estimated catchment area 112 ha less lake area 41.6 ha.

Table 8 (cont.): Lake Puketiirini (Weavers).

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
Pest fish					
3a. Pest fish control by intensive netting. Cost may be partially recovered through commercial harvesting (agency driven) of pest fish	$70,000 initial control then $30,000 per annum[lllll]	1	$70,000 + $30,000 per annum	Flow on effects for reduced internal nutrient loading, improved water clarity and habitat for submerged plants	Low to moderate.[mmmmm]
3b. Selective fish pass for tuna, lamprey, iinanga and other galaxiids (whitebait)/pest fish barrier	Up to 5 m ramp $50,000 + annual maintenance $10,000[nnnnn]	1	$50,000 + annual maintenance $10,000	Allows upstream fish passage. Tuna passage to a pest fish controlled habitat is likely to afford benefits for the tuna fishery. Upstream passage for smelt, mullet and trout will be blocked. A fish passage to allow native but not exotic fish would require further research.	Moderate. [ooooo]
3. Total (OPTION 2)			**$50,000 + $110,000 operating**		
Weed control					
4a. Weed control using herbicide	$1,600/ha for diquat product and application	2.8 ha[ppppp]	$4,480 + consent costs + annual maintenance	Reduced interference with recreational activities, access. No/minimal impacts on marginal and native submerged vegetation.	Moderate.[qqqqq]

[lllll] Based on cost estimated by DOC for Serpentine Lakes. (See Lake Serpentine Management Action Plan report.)
[mmmmm] Difficult to capture due to lake depth, unknown risk of flooding allowing passage of pest fish from Lake Waahi.
[nnnnn] As estimated by Dr. Jacques Boubée, NIWA.
[ooooo] Unknown risk of flooding allowing passage of pest fish from Lake Waahi.
[ppppp] Estimated area of *Egeria densa* and *Ceratophyllum demersum* weed beds averaged at 10 m wide around lake perimeter of 2.803 km.
[qqqqq] Risk of reinvasion from Lake Waahi and from recreation boat traffic likely to be high.

Table 8 (cont.): Lake Puketiirini (Weavers).

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
4a. Total (OPTION 2)			**$4,480 operating**		
4b. Stock grasscarp for weed eradication	$25 per 25 cm fish, 40 fish per vegetated ha + AEE and containment costs	2.8 ha	$2,800	Eradication of weed within 2–5 years, but impacts on marginal vegetation values, including native vegetation, will occur until fish can be removed (questionable) or attrition by mortality (15–20 years).	Moderate.[rrrrr]
4b. Total (OPTION 3)			**$2,800**		
Erosion					
5. Reduce shoreline disturbance by boater speed limit or access to shoreline; plant 2 m marginal reed beds around lake	$20,300/ha[sssss]	0.56 ha	$11,370	Current extent of marginal plants unknown. Enhance native vegetation fringe around lake, improved aesthetics and habitat for waterfowl.	Moderate.[ttttt]
5. Total (OPTION 3)			**$11,370**		
Access					
6. Public access to lake, picnic area	$5k[uuuuu]	1	$5k + $25k per annum maintenance for all public facilities	Enhanced public access and recreational facilities. Current facilities include access, car park, toilets, two jetties and a slipway.	High.

[rrrrr] Re-establishment risk from Lake Waahi and from recreation boat traffic likely to be high.
[sssss] Estimated costs root trainer 10,000 plants ha ($20,300 planted) + maintenance to year 3 ($13,600/ha) from Wildlands Consultants Limited. These estimates exclude management costs, plant delivery costs, travel and expenses.
[ttttt] Little other suspended sediment or nutrient loading sources.
[uuuuu] Based on cost estimates from Waikato District Council for similar projects completed by Council.

Table 8 (cont.): Lake Puketiirini (Weavers).

Action	Costs			Benefit	Certainty of outcome
	Cost item	Quantity	Total cost		
6. Total (OPTION 2)			**$5,000 + $25,000 operating**		
Monitoring					
7a. Lake monitoring using LakeSPI	$2,100	1	$2,100	Monitor native and exotic submerged vegetation as an indicator of lake health.	High.
7a. Total (OPTION 2)			**$2,100 operating**		
7b. Lake monitoring using LakeSPI and Trophic Lake Index	$2,100 pa + $9,235 pa for four visits	1	$11,135	Monitor native and exotic submerged vegetation as an indicator of lake health plus monitor Trophic Level Index as an indicator of lake health.	High.
7b. Total (OPTION 3)			**$11,235 operating**		

Table 9: Summary of estimated costs for six example lakes, giving ranges based on three restoration options.

Lake	Size	Option 1			Option 2				Option 3			
	ha	Upper			Lower	Upper			Lower	Upper		Upper
		CAPEX	OPEX	Frequency of OPEX *ys*	CAPEX	CAPEX	Duration of OPEX *ys*	OPEX	CAPEX	CAPEX	Duration of OPEX *ys*	OPEX
Ohakurii	940	$88,250	$3,733	3	$4,444,975	$4,444,975	3	$33,333	$8,094,025	$223,695,225	3	$44,042,400
			$25k	30			30	$792,352			30	$20,804,766
Serpentine	10	$0	$0	3	$469,045	$485,545	3	$17,067	$2,622,840	$3,170,840	3	$371,733
			$0	30			30	$127,709			30	$224,085
Puketiirini	42	$0	$0	1	$90,000	$90,000	1	$70,000	$932,800	$944,168	1	$70,000
			$0	3			3	$7,467			3	$186,667
			$25k	30			30	$72,084			30	$91,374
Ohinewai	17	$0	$0	1	$220,750	$220,750	1	$100,000	$1,142,120	$4,746,220	1	$0
			$0	3			3	$9,600			3	$836,800
			$0	30			30	$103,403			30	$140,476
Otamatearoa	5	$15,750	$2.4k	3	$152,677	$152,677	3	$3,013	$189,817	$641,372	3	$108,000
			$0	30			30	$27,465			30	$49,317
Whangapee	1,079	$37.5k	$0	1	$17,258,111	$17,258,111	1	$0	$70,381,575	$415,939,260	1	$0
			$8k	3			3	$3,100,000			3	$77,977,520
			$0	Yr 4 on			Yr 4 on	$793,100			Yr 4 on	$793,100
			$0	Yr 11 on		$518,400	Yr 11 on	$172,640		$952,000	Yr 11	
			$0	30			30	$480,877			30	$12,390,378

Table 10: Estimated costs for restoration of selected shallow Waikato lakes, by lake type.

Lake type	Number	Lake	Lake size	Option 2			Option 3		
	(of lakes)		(ha)	CAPEX	Duration of OPEX *ys*	OPEX	CAPEX	Duration of OPEX *ys*	OPEX
Hydro	1	Ohakurii	940	$4,444,975	3	$33,333	$13,483,025	3	$33,333
					30	$752,099		30	$761,234
Peat	4	Serpentine	100	$485,545	3	$17,067	$2,943,340	3	$371,733
					30	$127,709		30	$201,335
		3 generic peat lakes	600	$1,214,588	1	$210,000	$6,412,988	1	$0
					3	$102,400		3	$102,400
					30	$426,610		30	$785,263
Dune	2	Otamatearoa	5	$157,055	3	$3,013	$194,195	3	$13,947
					30	$27,465		30	$37,924
		1 other dune lake	5	$157,055	3	$3,013	$194,195	3	$13,947
					30	$27,465		30	$37,924
Large riverine	2	Whangapee	1,079	$2,142,436	3	$215,600	$32,654,170	3	$4,789,600
					Yr 4 on	$46,270		Yr 4 on	$46,270
					Yr 11	$518,400	$952,000	Yr 11	$0
					30	$290,765		30	$1,932,051
		Waahi	445	$432,890	3	$38,000	$7,146,844	3	$4,624,000
					Yr 4 on	$2,800		Yr 4 on	$2,800
					Yr 11	$177,829	$443,658	Yr 11	$0
					30	$254,624		30	$523,610
		Total CAPEX		$9,034,544			$64,424,416		

6.1 Cost abatement

Abatement costs for restoring six shallow lakes have been calculated. Costs are based on total capital and operational costs over 30 years discounted at eight percent. Operational costs for planting have been estimated over three years. The difficulty in identifying specific environmental outcomes for each lake resulted in using dollar per hectare restored comparisons. Abatement costs have been calculated for both restoration options 2 and 3.

Table 11: Total and per hectare costs for restoring shallow lakes under restoration option 2.

Lake name	Lake size (ha)	Net Present Value (NPV) $	$ per ha
Lake Ohakurii	940	13,121,748	13,960
Lake Puketiirini	42	978,897	23,531
Lake Whangapee	1,079	37,274,443	34,558
Lake Ohinewai	17	1,485,817	87,043
Lake Otamatearoa	5	458,328	94,113
Serpentine Lakes	10	1,931,276	186,597

For option 2, the most cost-effective per hectare combined restoration actions are Lake Ohakurii and Puketiirini. The most expensive per hectare action to restore are the Serpentine Lakes – by a factor of nearly 14 times when compared to the cheapest action. This is caused by the relative high restoration costs for any particular lake and the small size of the Serpentine Lakes. Lake Whangapee and Ohakurii are relatively cost-effective to restore, because of the large size of these lakes averaging around 1,000 hectare each, whereas all other lakes are relatively small, averaging between five to 42 hectares.

In terms of total costs, the most cost-effective actions are to restore Lake Otamatearoa and Puketiirini. By far the most expensive restoration is Lake Whangapee. This cost comparison can be used if the per hectare comparison is thought to be limiting in terms of environmental improvements achieved as a result of restoration.

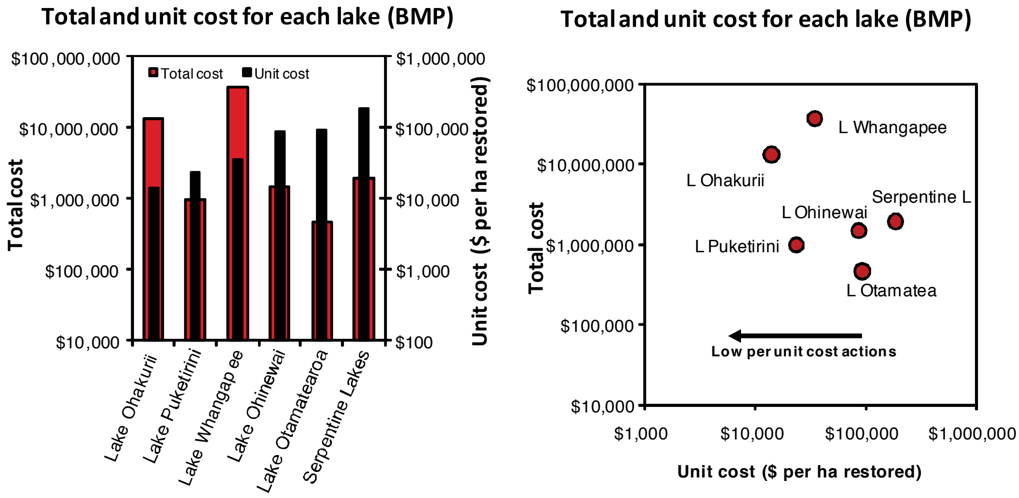

Figure 1: Total and per hectare costs for restoring shallow lakes under restoration option 2.

The table below shows the total capital and operational costs for restoring all six shallow lakes for the EBMP scenario.

Table 12: Total and per hectare costs for restoring shallow lakes under restoration option 3.

Lake name	Lake size (ha)	Net Present Value (NPV) ($thousands)	$ per ha
Lake Puketiirini	41.60	2,438	58,612
Lake Otamatearoa	4.87	1,427	293,097
Lake Ohinewai	17.07	8,133	476,427
Lake Whangapee	1,078.62	597,299	553,762
Lake Ohakurii	939.98	554,842	590,270
Serpentine Lakes	10.35	6,417	619,967

For option 3, the most cost-effective per hectare combined restoration action is Lake Puketiirini followed by Lake Otamatearoa. The latter is more expensive to restore per hectare by a factor of five due to the smaller size of this lake. The most expensive per hectare action to restore are the Serpentine Lakes and Lake Ohakurii, followed by Lake Whangapee and Ohinewai. Most lakes have similar per hectare abatement costs apart from Lake Puketiirini and Otamatearoa, which are the most cost effective to restore on a per hectare basis.

In terms of total costs, the most cost-effective actions are to restore Lake Otamatearoa and Puketiirini. By far the most expensive restoration actions are Lake Ohakurii and Whangapee, by a factor of between 68 to 73 than the next most cost effective option (Lake Ohinewai).

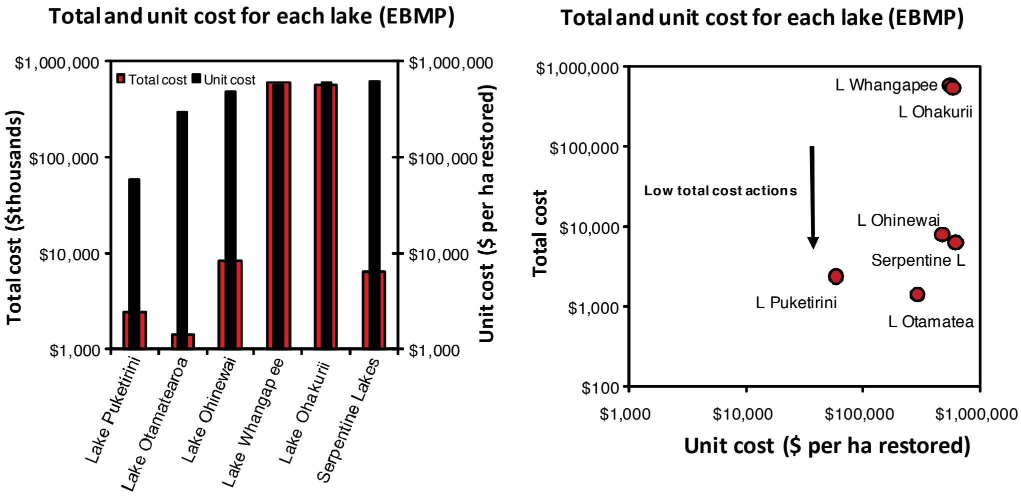

Figure 2: Total and per hectare costs for restoring shallow lakes under restoration option 3.

It is difficult to compare both options 2 and 3 in terms of costs, as there is a very large difference in total restoration costs and related actions. However, to implement option 3, costs are larger for all lakes – by a factor of between three and 14 times more expensive on a per hectare basis.

An important point is that lake restoration activities will interact with and be affected by other restoration actions. For example, if riparian fencing and protection is not undertaken in the upper catchment, nutrient rich water will continue to flow into the lakes downstream hampering any attempts to control nutrients within the lakes. Therefore the cost of undertaking those other restoration activities needs to be considered in conjunction with the costs identified here for lake restoration.

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