Restoration Plan for Lake Horowhenua

Collation of inter-related projects

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Cover Photo: Discussions between members of Lake Horowhenua Trust, the Domain Board, Horizons Regional Council and NIWA scientists beside the weir on the Hokio Stream. [Photo by Max Gibbs].

Unless stated otherwise, all photos and diagrams in this report are by Max Gibbs.

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Executive summary

The restoration of Lake Horowhenua will not happen by itself.

Restoration requires an understanding of the causes of the degradation of the lake and of the 'tipping points' where small management interventions may reverse or prevent further degradation. It requires an action plan to implement key management strategies that will improve lake water quality and manage expectations of success, such as achieving a specified water quality level or goal within a specified time frame. The restoration action plan need to be affordable with the cost burden shared between all partners – government, industry and the community.

The causes of the degradation of the lake have been defined in a review (Gibbs 2011).

Subsequent discussions between Horizons Regional Council (HRC), the National Institute of Water and Atmospheric Research (NIWA) and community leaders have identified a number of tipping points and management actions that would improve the long-term water quality of the lake. Horizons Regional Council commissioned NIWA to bring together and estimate the cost of a series of 11 management actions within the context of a discussion document. This report presents details of these management actions and their likely cost.

The degradation of Lake Horowhenua is caused by nutrients derived from the catchment accumulating in the lake. Historically, treated sewage effluent was discharged into the lake. That discharge ceased in 1987 and the review of the lake indicated that the water quality began to improve. However, intensification of farming —both dairy and market gardening — in the lake catchment has been accompanied by a rise in the external nutrient and sediment loads on the lake with a concomitant decrease in water quality.

The order of priority for implementing the management actions should be to reduce or turn off the external load of nutrients to the lake and to monitor the lake water quality to assess the effectiveness of these management actions. Monitoring is important as it allows adaptive management to improve efficiencies in the actions and it allows an assessment of the changes in lake water quality, thereby providing the measure for success. Community buy-in to the restoration of the lake is important because without it the restoration plan cannot succeed. To maintain community interest, the results of the monitoring, in terms of how the recovery is progressing, should be published in an annual lake 'report card'.

Additional actions would see the nutrient load in the groundwater intercepted by riparian buffer zones, physical removal of nutrients reaching the lake by harvesting the lake weed and skimming algal blooms, and preventing the introduction of new species of exotic weed. Algae are grazed by zooplankton, which are predated by pest fish. Actions that reduce the pest fish numbers will reduce the algal biomass by increasing zooplankton grazing pressure. Restoration of the lake includes actions that would see a return of native fish species to the lake.

A long term management strategy would see the primary cause of the lake degradation modified — the weir on the Hokio Stream outlet. This structure eliminated the natural cleansing process of flushing, effectively turning the lake into a sediment trap. Consequently, the lake retains more nutrients than it loses and the calm water allows sediment

accumulation and excessive weed growth. Making changes to the weir requires a change in law, thereby classifying this management action as a strategic long-term project.

The following is a list of the proposed management actions in order of priority. The priorities are based on urgency for lake restoration and for the prevention of further degradation through introduction of alien species. Costings are best estimates.

Priority management actions that require urgent consideration:

	Annual costs	**One-off costs**
Enhanced monitoring, (Lake buoy / met station)		$45,000
(Lake monitoring)	$18,400 pa	
(Stream monitoring)	$48,000 pa	
Public education – annual lake report cards	$5,000 to $15,000 pa	
Farm environmental plans		$75,000 to $150,000
Boat treatment and weed containment	$2,000 pa	$6,000

General management actions that can be implemented at any time:

Stormwater diversion – spill drain		$15,000
Riparian enhancement (Lake – plants only)		$2,000 to $6,000 /km
Riparian shading (Streams)		$9,000
Weed harvesting (Hireage)	$148,000 to $258,000 pa	
or (Capital expenditure)		$50,000 to $200,000
(Running cost)	$40,000 to $60,000 pa	
Enhanced predation (top-down), (2 year plan)	$6,000 pa	
Fish Pass (Option 1: Baffled ramp)		$35,000
or (Option 2: Nature-like channel)		$80,000

Long-term:

Lake level management (Law change)		$50,000*
(Capital expenditure)		$200,000 - $1 million
(Running cost)	$5,000 to $10,000 pa	

(* = guess)

1 Introduction

Lake Horowhenua is a hypertrophic lake as defined by lake classification (Table 1-1) and the trophic level index (TLI) (Burns et al. 1999, 2005). A recent review of the lake and the prospects for addressing water quality issues (Gibbs 2011) identified many of the factors that caused and continue to contribute to the degradation of the lake. Subsequent discussions with Horizons Regional Council (HRC) and the National Institute of Water and Atmospheric Research (NIWA) produced a set of 11 practical measures (actions) that could be implemented individually or in combination to improve the water quality of the lake. Horizons Regional Council has asked NIWA to collate these strategies into a single report that shows how each strategy will benefit/improve the lake water quality. The report is to also provide estimates of the cost for each strategy in order to obtain the appropriate level of funding.

1.1 Background

The Lake Horowhenua review (Gibbs 2011) summarised the history of the lake and the changes that have contributed to the degradation of the lake as follows:

- Pre-European times, Lake Horowhenua was a clean-water supply and valued fishery for the Muaupoko iwi who lived in the coastal forest that surrounded the lake.
- It had a fluctuating water level and the lake bed was comprised of cobble and sand with many freshwater mussels present.
- Today the lake is highly degraded with a classification of hypertrophic (Table 1-1), the lake bed is mud and silt, the fishery has declined and there are very few freshwater mussels left.
- It has a water quality Trophic Level Index (TLI) of 6.7 and it is ranked 107 out of the 116 monitored lakes in New Zealand.

Table 1-1: Lake classifications, trophic levels and values of the four key variables that define the different lake classifications. (Chl *a* = chlorophyll *a*, TP = total phosphorus, TN = total nitrogen. From Burns et al. (2005).

Lake classification	Trophic level	Concentration (mg m^{-3})			Secchi depth (m)
		Chl *a*	TP	TN	
Ultra-microtrophic	0.0 – 1.0	0.13 – 0.33	0.84 – 1.8	16 - 34	24 - 31
Microtrophic	1.0 – 2.0	0.33 – 0.82	1.8 – 4.1	34 - 73	15 - 24
Oligotrophic	2.0 – 3.0	0.82 – 2.0	4.1 – 9.0	73 - 157	7.8 - 15
Mesotrophic	3.0 – 4.0	2.0 – 5.0	9.0 - 20	157 - 337	3.6 – 7.8
Eutrophic	4.0 – 5.0	5.0 – 12.0	20 - 43	337 - 725	1.6 – 3.6
Supertrophic	5.0 – 6.0	12.0 – 31.0	43 - 96	725 - 1558	0.7 – 1.6
Hypertrophic	6.0 – 7.0	>31	>96	>1558	< 0.7
Lake Horowhenua	6.7	211	230	3080	0.79

- The poor water quality is due to extremely high nitrogen (N), phosphorus (P) and suspended sediment concentrations in the lake, as well as the shallow depth of the lake.

- It has a substantial lake weed problem and experiences cyanobacteria blooms in summer (Figure 1-1). Cyanobacteria (blue-green algae) blooms are smelly and release toxins which cause skin irritation and other health issues, can be lethal to dogs and, in extreme conditions, could be lethal to small children[1]. Consequently, cyanobacteria blooms cause the lake to be closed.

Figure 1-1: Lake Horowhenua with cyanobacteria bloom. The bright green patches are a cyanobacteria bloom drifting across the lake with the wind. [Image from Google Earth, 9 March 2011].

- Degradation of the lake is attributed to the clearance of the coastal forest, draining of swamps, uncontrolled access of stock to streams and the lake, and disposal of sewage effluent in the lake between 1962 and 1987.

[1] Under warm calm conditions, cyanobacteria can form a surface scum that drifts inshore and accumulates in the edge water. As the cyanobacteria die they release cyanotoxins into the edge water. Under scum conditions, very high concentrations of cyanotoxins can develop. Although there are no recorded cases of human death from cyanotoxins in New Zealand, people can become unwell, experiencing skin rashes and liver and respiratory problems through contact with the cyanobacteria or breathing the fumes. Cyanobacteria regularly bloom in Lake Horowhenua in late summer releasing the cyanotoxin, microcystin. Cyanotoxins at the edge of the lake have been measured at up to 36,000 ug/L (Wood et al. 2006) – many, many times greater than the recommended action level of 12 ug/L (Ministry for the Environment and Ministry of Health. 2009). The toxin remains a health risk for many days after the bloom has dissipated. The health risk increases with increasing exposure or contact time.

- A weir installed on the Hokio Stream lake outlet in 1956 to control the water level for the purpose of defining the lake boundary for ownership, has altered the annual flushing cycle, causing sediment to accumulate in the lake. The lake has in-filled by around 40 cm since 1950.
- No fish pass was built over the weir and the fishery has declined, with some diadromus species (which spend part of their life cycle at sea) are no longer present and others greatly reduced in abundance.
- Sewage effluent was discharged into the lake from the 1960s to 1987, exacerbating the degradation, enhancing nutrient loads, especially P, and further accelerating sedimentation.
- Removal of the sewage discharge in 1987 saw the lake begin to recover and the P levels in the sediment have declined by 47% to the present. However, at this rate of recovery it will take about 120 years to achieve a 95% reduction in P, assuming that there is no increase in nutrient loads from land.
- The water quality improved to supertrophic (Table 1-1); the TLI fell from 6.28 in 1989 to 5.88 in 2000.
- Since the early 2000s, the water quality has declined once more to hypertrophic, with the TLI increasing from 5.88 in 2000 to around 6.7 in 2008.
- This decline is attributable to intensification of market gardening and dairy farming in the catchment. Total N concentrations in the Arawhata Stream increased from a mean of 10.5 g m^{-3} in 1988/89 to 13.6 g m^{-3} peaking at 21.7 g m^{-3}, in 2008/09, while total P loads in the Mangaroa Stream increased by about 300%. The P increases are associated with particulate matter e.g., soil.

The review determined that:

- The weed problem is driven by the external N load on the lake via streams and groundwater. Evidence indicates that the N concentration in the lake reduces to zero during the spring weed growth and stays low while the weeds are present.
- Cyanobacteria blooms are driven by P released from the sediments under anoxic conditions. It is estimated that 1 kg of P can stimulate the growth of 1100 kg of algae.
- Because the lake is shallow and well mixed, the lake doesn’t develop anoxic conditions at the sediment surface in the way that occurs in deeper lakes. Anoxic conditions develop when the weed beds collapse and form a barrier to oxygen reaching the sediments in late summer.

In simple terms, manage the weed to reduce or eliminate the cyanobacteria bloom problem.

The review concluded that:

- Restoration of Lake Horowhenua is possible but requires the catchment nutrient sources to be reduced, the internal nutrient loads to be managed and the weir operation to be modified.
- The restoration processes can be implemented in stages with the highest priority being a reduction in the sources of nutrient and sediment from the catchment.

1.2 Restoration options

Fundamental to the restoration of Lake Horowhenua is an understanding of how the lake works and how it responds to changes in the catchment (Gibbs 2011). For example, the high hydraulic conductivity in the Pleistocene Ohau gravel fan underlying the lake catchment is critically important to the lake water quality and the restoration of the lake. The high hydraulic conductivity allows groundwater to reach the lake from almost anywhere in the catchment within a year. This means any excess nutrient lost from land in the catchment by leaching or runoff essentially goes directly to the lake. On the other hand it means that management strategies to reduce nutrient loads in the catchment have a high probability of success within a relatively short time frame i.e., years rather than 10s of years.

Because the soil structure has a high iron content, which can adsorb or bind phosphorus, the groundwater and surface stream inflows have low phosphorus but very high nitrogen content. Globally, about 80% of the phosphorus entering a lake comes in the form of particulate matter (Figure 1-2) – often associated with the fine soil washed off farm land, cropland and urban roads. The review (Gibbs 2011) identified that in 1988/89 about 80% of the phosphorus entering Lake Horowhenua came via the Queen Street storm water drain. Recent (2000/09) data from HRC indicates that proportion is declining while the proportion in streams is increasing.

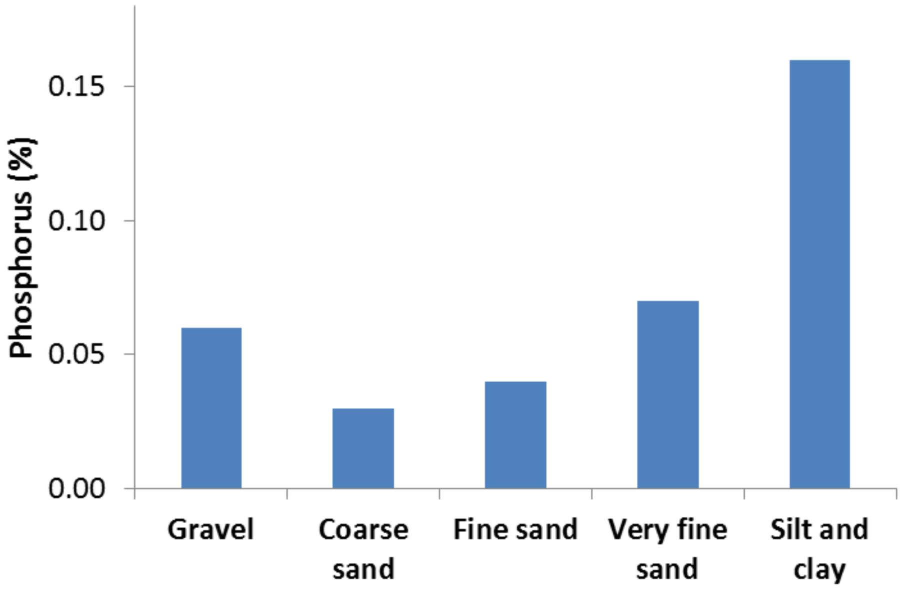

Figure 1-2: Phosphorus content (%) in different size fractions of particulate material. Data from Breault et al. (2005).

The increase in stream phosphorus loads is as particulate material which is consistent with more bare land being available for erosion (wind and water) as the area in cultivated land for market gardening increases. Much of the market gardening increase has been near the Arawhata Stream but cultivated land extends across much of the catchment (Figure 1-3).

To assist with understanding how the lake works and how it will respond to a specific management strategy, the processes that interact need to be identified and the connectivity between other processes defined. A conceptual linkage diagram for Lake Horowhenua was developed (Figure 1-4) to help inform decisions on what restoration measures to use.

The conceptual linkage diagram is read by following the linkage arrows from the action boxes (blue rectangles) to the response/effect cells (round-cornered boxes). These response/effect cells can be affected by multiple actions (arrows in) and they can produce further actions (arrows out) that link to other response/effect cells. The end response/effect cell (no arrows out) is the desired result. The shorter the pathway, the more direct the effect of an action.

Figure 1-3: Lake Horowhenua catchment land use. Extensive areas of bare land associated with market gardening occur near the Arawhata Stream at the southern end of the lake but also occur throughout the catchment east of the lake. [Image from Google Earth; 9 March 2011].

The conceptual linkage diagram identifies all the actions that need to be taken or considered to achieve the desired result. It also reinforces the idea that no one action is likely to restore the lake the desired condition. If an efficiency term was introduced to each response/effect cell, it would be possible to estimate/predict how effective any given action, or combination of actions, would be in achieving the desired result. This would allow managers to select those actions that gave the 'biggest-bang-for-the-buck" as top priorities. It would also allow managers to assess the overall effectiveness of a combination of restoration measures and thus manage the public expectation of success. Unfortunately, as yet there is insufficient data available for Lake Horowhenua and its catchment to provide the efficiency terms and, consequently, the conceptual linkage diagram (Figure 1-4) has been used as a map together with best scientific practice to develop restoration strategies for the lake water quality.

In this conceptual linkage diagram, the action of sediment capping has not been included. Sediment capping to inactivate bioavailable phosphorus in a lake is proven technology for reducing the occurrence of toxic cyanobacteria blooms, but requires adding a foreign substance to the lake (e.g., Cooke et al. 2005; Gibbs et al. 2011). Before this tool was used in the lake, it would require testing to determine the efficacy of the product used, when to apply it, at what dose rate, and, above all, to demonstrate that the product was safe and would not affect human health by transfer through the food chain.

Discussions between HRC and NIWA based around the conceptual linkage diagram (Figure 1-4) produced a set of 11 conceptual ideas as management actions that are practical and affordable, and that could be implemented individually or in combination to improve the water quality of the lake. The management actions produced are:

- Farm environmental plans
- Stormwater diversion – spill drain
- Riparian enhancement (lake)
- Riparian shading (streams)
- Weed harvesting
- Lake level management
- Enhanced predation (top-down)
- Fish pass
- Boat treatment and weed containment
- Enhanced monitoring
- Public education – lake report cards.

The ideas are listed and presented in the following sections of this report in a logical sequence starting with land-based and lake actions followed by monitoring to assess effectiveness of these actions and the presentation of the report card that says how well the lake is doing. This order is for convenience in this report. The actions can be implemented in any order.

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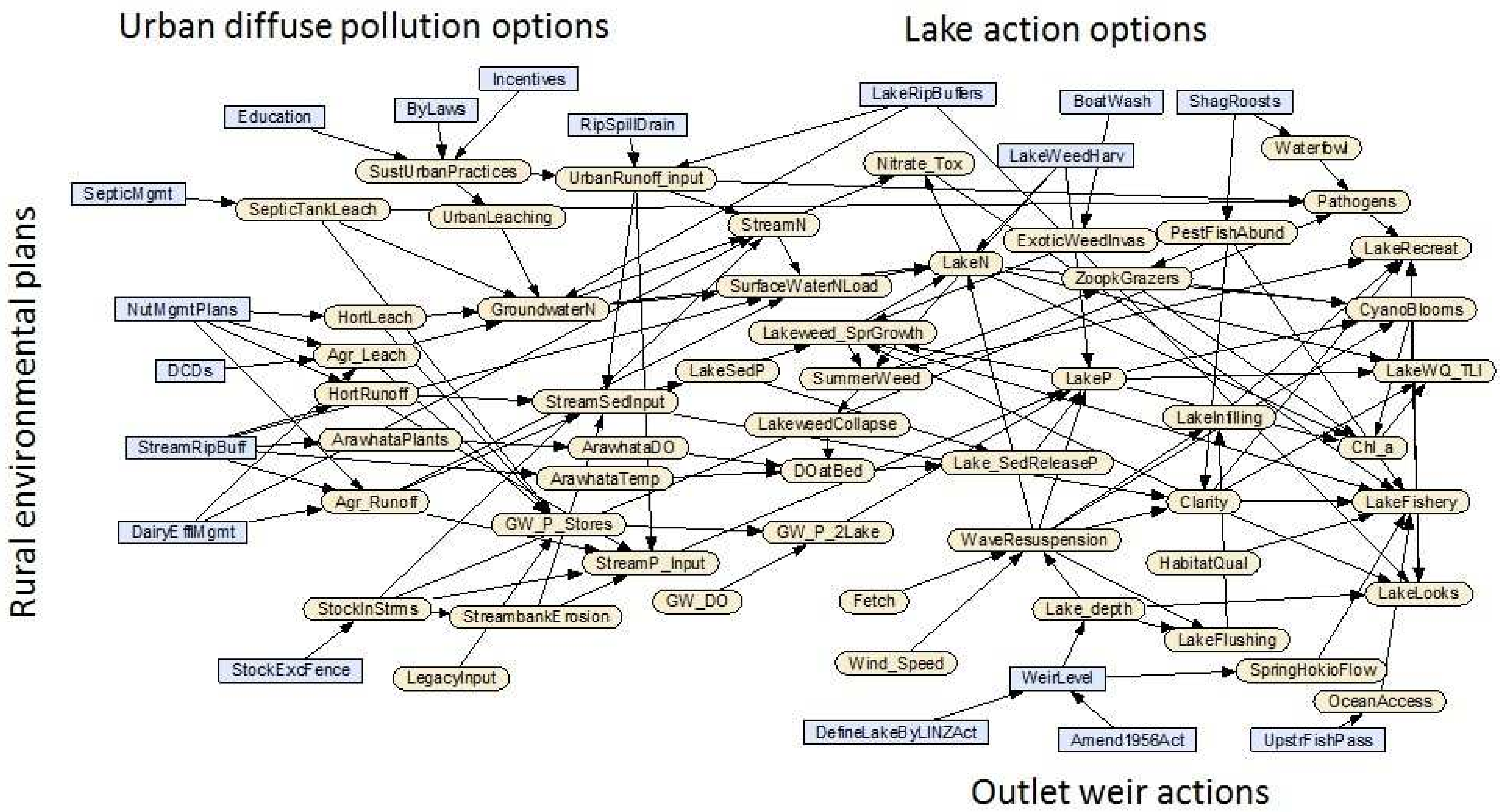

Figure 1-4: Conceptual linkage diagram for Lake Horowhenua. Rectangular boxes are actions, rounded corner boxes are response/effect cells.

The management of Lake Horowhenua is vested in the Domain Board (under the authority of the Manawatu Catchment Board), which was established in 1956 by act of Parliament — Reserves and Other Lands Disposal (ROLD) Act 1956, or simply the ROLD Act 1956. All work on the lake must have prior approval of the Domain Board and the board members have the responsibility to follow the law as set out in that act. Of the restoration actions proposed, only one, “lake level management”, falls outside the wording of the act. It will require an amendment to the act before that work can be implemented.

1.3 ROLD Act 1956

1.3.1 Problem

Under the ROLD Act 1956, a weir was installed on the Hokio Stream outlet from Lake Horowhenua to hold a constant lake level as a geographical reference for the legal boundaries defining land ownership of and around the lake. Section 18(10) [formerly (j)] of the ROLD Act 1956 states “The Manawatu Catchment Board shall control and improve the Hokio Stream and maintain the lake level under normal conditions at thirty feet above mean low water spring tides at Foxton Heads: provided that before any works affecting the lake or the Hokio Stream are undertaken by said Catchment Board, the prior consent of the Domain Board constituted under this section shall be obtained: …”

The effect of the weir was to turn the lake into a sediment trap eliminating a key natural cleansing process and to block free access of the lake’s diadromus fish population to the sea. The constant lake level, maintained by the weir, and the lack of a fish pass over the weir are major impediments to the restoration of the water quality and native fishery in Lake Horowhenua. It should be noted that the construction of a fish pass was not prohibited by the act, and was can be addressed within the existing wording of the act.

The key issue is the constant level. It prevents natural flushing processes which would naturally cleanse the lake if the weir was not present or if the weir level could be adjusted.

1.3.2 Solution

The need for a constant lake level to define legal land ownership boundaries is obsolete as it has been superseded by the 2009 legal description of the lake and land boundaries as recorded on CFR WN855.22, Survey Office Plan 23584.

For the restoration of Lake Horowhenua and the development of a sustainable management strategy for the lake, an amendment to the ROLD Act 1956, Section 18(10), is required. A suggested amendment to Section 18(10) would be to replace the clause [“… *and maintain the lake level under normal conditions at thirty feet above mean low water spring tides at Foxton Heads: …*”] with the following clause *[“… through the use of lake level control and other measures:* …”]. The amended wording will allow remedial actions such as enhanced flushing to reduce the sediment and nutrient load in the lake, selective removal of cyanobacteria blooms by surface skimming over the weir, increased habitat for the native freshwater mussel (kakahi) and improved access for native fish.

The ROLD Act 1956 is a bill which is brought before Parliament each year and is usually amended annually to accommodate small changes to law, such as the suggested amendment. The ROLD Act is currently before Parliament but has stalled since 2009 and is due to be read in Parliament in 2012. The proposed amendment to Section 18(10) of the act requires support from all stake holders and a sponsor to get it added to the next revision of the ROLD Act.

1.4 Funding

At this time, exact costs for implementing the concept idea projects is unknown and a best estimate approach has been adopted. Where possible, costs have been estimated based on past experience of similar projects. For other concept ideas, the costs have been given a broad range as a “ball-park” figure and would require further work to refine those figures. As presented, the costs are only indicative.

The concept ideas focus on the restoration of Lake Horowhenua through short- and long-term measures which will involve the whole catchment as well as targeting some site-specific measures. Consequently, there are potentially a number of partners to fund and support projects. These include Horizons Regional Council, DairyNZ and Horticulture NZ through grants and other funding initiatives. There are some projects where iwi and community volunteer workers might assist with the implementation, e.g., the enhancement of the lake riparian buffer zones. The modification of the weir may require investment from central government.

2 Concept Idea Projects

2.1 Farm environmental plans

Problem

Lake Horowhenua is suffering from an excess of nutrients (nitrate and phosphorus) and sediment. Part of this problem is historical, but there continues to be an elevated input of nutrients and sediment from the catchment.

Land use in the catchment is a mixture of urban, dairy, market gardens and lifestyle blocks. There are significant inputs of nutrients and sediment to the lake from dairy farms and market gardens, with dairy farms mainly losing nutrients, and market gardens losing a mixture of nutrients and sediment.

Solution

Management practices on each of the dairy farms and market gardens within the catchment are likely to be different, causing nutrients/sediment to enter waterways/groundwater, and then the lake, via different pathways. As such, an approach that identifies the activities leading to nutrient/sediment losses from each property, and then recommends a property-specific set of solutions needs to be used. It is proposed to prepare an Environmental Management Plan (EMP) for each dairy farm and the key market garden operations in the catchment.

Preparation of the EMPs will be a joint effort involving Horizons, DairyNZ, Horticulture NZ, and contractors. Each property will be visited, land use and type assessed, nutrient/sediment losses quantified, and solutions recommended. These solutions will be a series of best practices, tailored for the property in question. Once prepared, the landowner/manager would be walked through the EMP, and an action plan to give effect to the EMP would be prepared. Where possible, funding will be provided to support implementation of the EMP recommendations.

Costs

The estimated cost of each EMP ranges between $3000-$6000, depending upon the level of detail required, and the size and complexity of the property. A total of 25 plans would be produced, which would cover all of the dairy farms (8), and the main market gardening operations. There are more market gardens than this, but they tend to be moved around the catchment, on leased land.

The total cost of preparing the EMPs would therefore be in the order of $75,000-$150,000. The cost of implementing the EMPs cannot be estimated until the EMPs have been produced. Actions falling out of the EMPs will range from very low/no cost changes to farming practice (e.g., till land across the slope), through to more expensive options such, as construction of sediment detention structures (in the order of tens of thousands of dollars).

The cost of the EMPs could be shared between partners including Horizons Regional Council and industry (DairyNZ/Horticulture NZ). Industry representatives would then be responsible for developing the action plans.

Potential Actions

Suggested actions that might be needed to reduce catchment nutrient loads include:

1. Excluding stock from direct access to the lake and all permanent streams with 5 m wide, fenced, buffer zones planted with native plants (Figure 2-1). A recent review of international research on buffers for sediment retention in agricultural landscapes (Yuan et al. 2009) found that removal efficiency increased with buffer width and decreased somewhat with land slope. This analysis found that the sediment trapping efficiency was at least 80% for all buffer widths of greater than approximately 5 m.

Figure 2-1: Stock exclusion fencing. The stock exclusion zone needs to be 5 m wide to keep the stock and their excrement and sediment from getting into the stream. For example, these North Island streams are fenced but the fences are unlikely to be effective because of the farm management strategies.

2. Reducing the use of fertiliser on farms, orchards, and home gardens (Section 2.11) within the lake groundwater catchment. With rapid transport of groundwater directly to the lake, any excess nutrients applied to the land are effectively being applied to the lake.
3. Reducing spray irrigation of wastewater pond effluent and / or whey onto farmland within the lake groundwater catchment – use constructed wetlands for nutrient removal and clean water for irrigation. A critical factor identified in the conceptual linkage diagram is that the groundwater has very low P concentrations, implying that it has high dissolved oxygen (DO) concentrations. Addition of carbon from overloading the land with effluent and whey could cause high oxygen demand which would reduce the DO concentrations in the groundwater and release the P that is bound to the iron oxides in the groundwater aquifers. This would load the lake with P at all times of the year and stimulate massive algal blooms.
4. Consider the use of stand-off pads and herd-sheds for dairy herds rather than pugging fields in winter. The effluent can be channelled into treatment ponds rather than releasing nutrients and carbon into the groundwater.

While most nitrogen enters the lake from the catchment in solution as nitrate, about 80% of the phosphorus enters the lake in particulate form attached to soil particles. This means that most phosphorus arrives in the lake during the few storm events each year that can erode even the flattest land (Figure 2-2). Recent trends in climate variability point to an increase in the frequency of high intensity rainfall event. Consequently, land management strategies should include measures to reduce soil erosion.

5. Replacing the practice of clearing drainage channels by digger with the use of sprays to control grasses and weeds. Both clearance methods leave bare soil exposed to erosion in rainy weather but the soil disturbance caused by the digger results in higher erosion rates than the undisturbed soil left after spray clearance.

6. Installing sediment retention ponds on the down slope extent of market gardens. This will trap much of the sediment that is washed off the cultivated land in rain storms and allows this valuable fertile soil to be returned to the field rather than be carried into the lake (Figure 2-2).

Figure 2-2: Crop-land erosion. High intensity rainfall can cause severe erosion even on almost flat land. Recovered soil from erosion path through the new planting shown in centre of photo. [From CD Farm Road 14/12/2011]

7. Till across the slope rather than down the slope (Figure 2-3) and leave grassy swales to transport the runoff water. This reduces the velocity of the runoff water on the cultivated land while the grassy swale armours the ground against erosion.

Figure 2-3: Soil erosion from furrows between crops. The clean furrows allow water velocity to increase down slope exacerbating erosion. Tilling across the slope would reduce the water velocity. [Photo from Kawiu Road 14/12/2011].

2.2 Stormwater diversion – spill drain

Problem

An excess of P in lake water favours the growth of blue-green algae (cyanobacteria) over all other algal species. In most lakes the P enters the lake from the catchment, often attached to soil and sediment particles in the stream and storm water inflows. In Lake Horowhenua, nutrient loads from the catchment via streams and groundwater are high in bioavailable N but low in P, resulting in P-limitation to algal growth i.e., any addition of P is likely to stimulate algal growth. The exception is the Queen Street storm water drain which, in 1989, was estimated to contribute more than 80% of the external P load to the lake in particulate form. The P stored in the sediment can be released under anoxic conditions in summer, and can be recycled again and again each year. It is that seasonal release of P from the lake sediments which results in cyanobacteria blooms in summer.

Lake Horowhenua also has a legacy of P from 25 years of sewage discharge into the lake stored in the sediments. Recent evidence (Gibbs 2011) suggests that this sediment load is slowly reducing through natural processes, i.e., the amount available for recycling decreases each year as some is flushed out of the lake when it is incorporated in algal cells. However, the new inputs of P from the Queen Street drain also accumulate in the lake sediments replenishing the amount of P in the sediment store that was lost via the flushing process, slowing the recovery of the lake. For the successful management of the P loads in Lake Horowhenua, the external P load must also be managed.

Solution

Divert the Queen Street storm water from the lake into a “spill drain” (Figure 2-4) which causes that water to flow slowly through the lake edge buffer zone.

At present, the discharge from the Queen Street storm water drain is jetted out into the lake where the P in that flow combines with P recycled from the sediments to stimulate cyanobacteria blooms in summer or accumulate in the sediments to be recycled. If the storm water flow is not jetted out into the lake, but retained within the lake riparian buffer zones, it cannot accumulate in the lake sediments.

To achieve this, the entire flow of the Queen Street storm water drain would be diverted into a spill drain along the landward edge of the riparian buffer zone or parallel with the lake shore between Queen Street and Makomako Road. Storm water from the Makomako Road drain could also be diverted into this drain. The spill drain would comprise two broad (about 1 m wide) shallow channels about 0.2 m deep and about 1 km long, about 1 m apart. The material taken from the channels would form a raised back to the rear channel to prevent water flowing inland (Figure 2-4). Actual dimensions would be determined by the equipment used to form the channels (e.g., grader blade width and separation capable of being mowed).

In operation, storm water would flow into the rear channel and fill that drain before spilling evenly along the entire length of the drain into the front channel and then from the front channel into the lake edge buffer zone. The effect would be that the high initial velocity of the storm water would be dissipated along the rear channel, allowing settling of some sediment and some infiltration. When the channel was full, water spilling from the rear channel into the front channel and subsequently from the front channel would be the less turbid surface water. This water would trickle into the riparian zone with insufficient velocity to cause erosion. Nutrients in the storm water would be available for plant uptake in the riparian zone. The channels themselves would have gravel beds and would be infiltration zones. The P in the storm water would be in contact with the iron-stone gravels, which would remove any bioavailable P from the water.

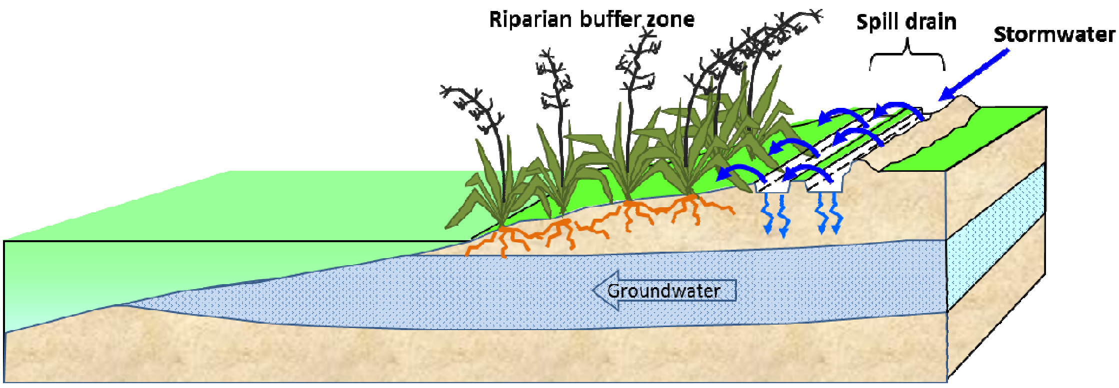

Figure 2-4: Schematic diagram of the spill drain concept. Stormwater discharged into the landward drain slows as it fills that drain before spilling over into the lakeward drain which, when full, spills into the riparian buffer zone and slowly trickles into the lake. Stormwater infiltrates into the ground from the spill drains and particulate material is trapped in the spill drains and the root zone of riparian plants.

Feasibility: The volumetric capacity of the spill drain would be about 400 m^3. The maximum flow encountered in the Queen Street Storm water drain during the 1988-89 study was 0.2 $m^3\ s^{-1}$. It would take about 30 minutes to fill both channels of the spill drain at that storm water discharge rate. The flow velocity from the Queen Street drain pipe, assuming half full at 0.2 $m^3\ s^{-1}$, would be around 40 cm s^{-1}, which is sufficient to move coarse sand. The velocity from the spill drain into the riparian buffer zone would be reduced to less than 0.5 cm s^{-1} which would allow all but the finest particulate material to sediment out.

Cost:

Assuming that purchase of land is not required, all permits were provided and that the standard roading machinery such as graders, diggers, rollers, compactors etc., can be used for this project, a nation-wide construction engineering firm suggests that the spill drain would cost about $15,000 to construct. Maintenance would be minimal with an annual clearance of silt and debris plus spraying of weeds to keep the spill drains free flowing.

Street sweeping

A literature survey of the sources of phosphorus in the stormwater indicate that most is in leaf litter and fine dust (Breault et al. 2005). Consequently, street sweeping at the end of extended dry period could be beneficial to reduce the P load on the lake. Suggested reductions in P loads from high efficiency street sweeping range from 17% to 80%, the differences being related to sweeping frequency, timing since last rainfall, road surface, stormwater infrastructure and urban versus commercial areas. This would require a separate study to determine the likely benefits to Lake Horowhenua.

2.3 Riparian enhancement (lake)

Problem

The shallow groundwater around Lake Horowhenua is enriched by nutrients with intensive farming (dairy, market gardening, cropping) and other sources such as septic tanks, urban gardens, etc. The shallow groundwater contributes more than 50% of the bioavailable nitrogen (N) to Lake Horowhenua. The free-flowing gravel aquifers around the eastern side of the lake conduct this N rapidly into the lake where it supports the spring growth of lake weed. Riparian plantings around the lake have the potential to intercept and remove much of that N before it enters the lake. Historically, the wetland margins of the lake would have had a diverse range of plants that could combine to remove nutrients before they entered the lake from the catchment. Deforestation and land drainage has largely eliminated the natural wetland margins. Recently, a riparian buffer zone of flax (*Phormium tenax*) or harakeke, with some trees and scrubs, has been planted around much of the lake (Figure 2-5). The flax in the riparian buffer zone also has an understory of tall grasses (e.g., *Dactylis glomerata*: cocksfoot) and exotic weeds (e.g., *Lythrum salicara*: purple loosestrife) interspersed with regenerating native wetland species e.g., *Juncus sp*. and *Carex sp*.) around the margins. While the flax plantings are well developed, they represent a monoculture of plants which are less efficient at N uptake than plantings with a greater diversity and more efficient root zone (Figure 2-6).

Solution

Enhance the existing riparian flax plantings with a variety of wetland vegetation, shrubs and trees that can tolerate different levels of soil saturation ranging from mostly dry (rushes and sedges e.g., *Juncus saraphorus*; *Cyperus ustuiatus*), through saturated (e.g., *Schoenoplectus tabernaemontani*; *Typha orientalis* Raupo), to deeper water emergent varieties (e.g., *Baumea* and *Eleocharis*).

Figure 2-5: Riparian buffer zone around Lake Horowhenua. Flax (*Phormium tenax*) with wide grassy spaces (left) and with woody species (right), and the understory of grass. [Photos 14/12/2011].

The advantage of having a diverse range of plants is that they each have characteristics which benefit the lake under different lake levels and degrees of soil moisture. For example, Raupo takes up large amounts of N in spring and mature plants provide nesting sites for water fowl. Decomposition of the leaf litter in autumn and winter causes localised areas of anoxia (no oxygen) around their roots, enhancing removal of nitrate from the groundwater through microbial denitrification to nitrogen gas. Raupo is best planted in the more sheltered areas.

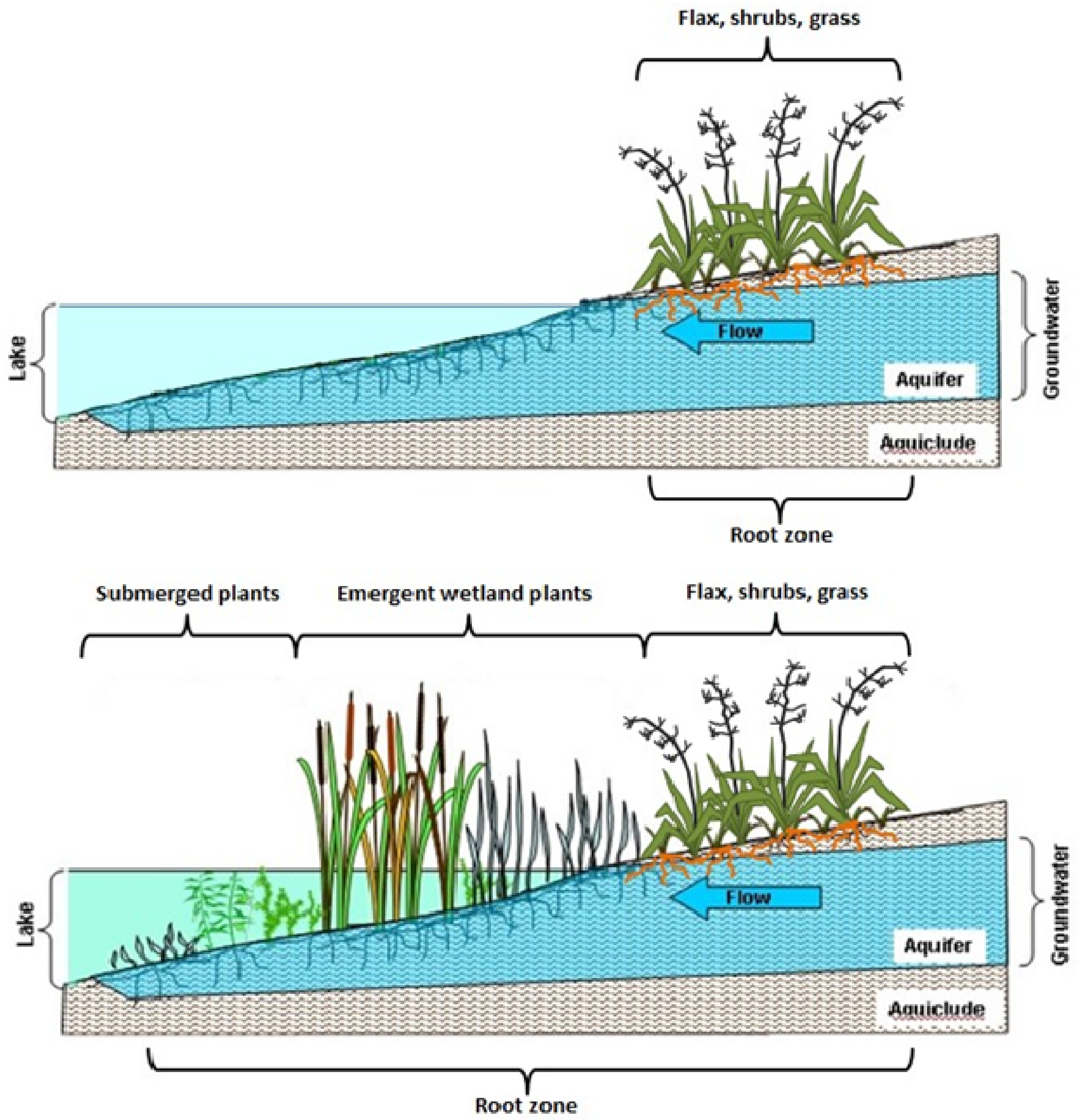

Figure 2-6: Schematic riparian buffer zone. Upper shows the present flax plantings. Lower indicates what enhanced plantings might look like. The enhanced plantings extend out into the lake and provide a greater area of root zone for nutrient uptake.

The addition of woody species in the riparian buffer zone provides a further dimension to the buffer zone in terms of habitat for birds and aesthetic landscape appeal. The list of preferred native plants (Table 2-1) will increase the diversity within the riparian buffer zone and thus improve its ecosystem function.

Table 2-1: Plants suitable for lake restoration. Selected native wetland plants that are emergent (E) or will tolerate wet conditions (W). Woody species provide height to the riparian buffer zone and most will tolerate wet conditions.

Plants suitable for lake restoration	
Native wetland species (damp to edge waters)	**Woody species used for riparian/lakeside plantings**
Carex maorica - tussock W	***Alectryon excelsa*** **-** titoki
Carex secta **-** giant swamp tussock W	***Coprosma robusta*** - karamu
Carex virgata - smaller swamp tussock W	***Cordyline australis*** - cabbage tree, ti kouka
Cyperus ustulatus - giant sedge (drier conditions)	***Dacrycarpus dacrydioides*** - kahikatea
Eleocharis acuta - sedge W / E	***Dodonaea viscosa*** - akeake
Isolepis prolifera - small bulrush W	***Laurelia novae-zelandiae*** - pukatea
Juncus australis **-** serrated tussock W	***Melicytus ramiflorus*** - mahoe
Juncus edgariae - common rush W	***Myoporum laetum*** - ngaio
Juncus sarophorus - tall rush (drier conditions)	***Olearia paniculata*** - akiraho
Schoenoplectus tabernaemontani - soft stem bulrush E	***Pittosporum eugenioides*** - lemonwood, tarata
Typha orientalis **-** raupo (Sheltered conditions) E	***Podocarpus totara*** - totara

Because the flax and grasses will shade out some of these species, care is needed when locating them in the wetland. The grass needs to be removed at each location before planting to give the wetland plants space to grow. Further information is available from the constructed wetlands guidelines (Tanner et al. 2006).

Cost

Much of the costs associated with enhancing the wetland plantings are labour. Many of the plants listed can be grown easily from seed and the use of the local seed would maintain the local genetic stock from around the lake. Trees and shrubs are more expensive depending on the size. Assuming a 5-m spacing for the trees and a wholesale cost of $10 to $20 per plant, the cost would be $200 to $400 per 100 m for trees. This equates to $2000 to $4000 for the section between Makomako Road and the Domain. The tall grasses would need to be sprayed to prevent smothering while the trees became established.

If purchased, the cost of wetland plants to enhance the existing riparian buffer zone may be around $2000 but with more plants per 100 m than the trees. Planting the trees and wetland plants may be a community project to save on labour costs and create opportunities for local engagement. The cost of plants for this project could be from $2000 to $6000 per lake-shore km depending on their source, size and whether the wetland plants can be locally grow. No estimate is made for the labour for planting.

The cost of this project would be revisited once a more detailed planting plan has been developed. The cost of developing a planting plan would be in the order of $2,000 to $4,000.

2.4 Riparian shading (streams)

Problem

Arawhata Stream, with its extremely high nitrogen concentrations, is by far the largest surface-water input to Lake Horowhenua under normal flows. However, there is evidence (Gibbs 2011) that Arawhata Stream’s high day-time temperature and low night-time dissolved oxygen during summer are likely to contribute to release of phosphorus from the lake bed sediments in the vicinity of the stream mouth. The high day-time temperatures are because the stream has no shade on its north-west bank. The shaded Patiki Stream has much lower day-time temperatures (Figure 2-7). This causes large diel (day versus night) variations in dissolved oxygen, due to the metabolism of a high biomass of in-stream plants photosynthesising during the day and respiring at night.

The stream temperature is similar to that of the lake during the day so that the flow enters the lake as a surface flow during the middle of the day when it is well oxygenated. However, at night the stream is cooler (higher density) than the lake and enters the lake as an underflow along the lake bed below the warmer surface water (Figure 2-7). This is problematic because it appears likely that the stream water has very low dissolved oxygen at night, so that its inflow worsens the problem of low DO at the sediment-water interface that drives phosphorus release in the lake.

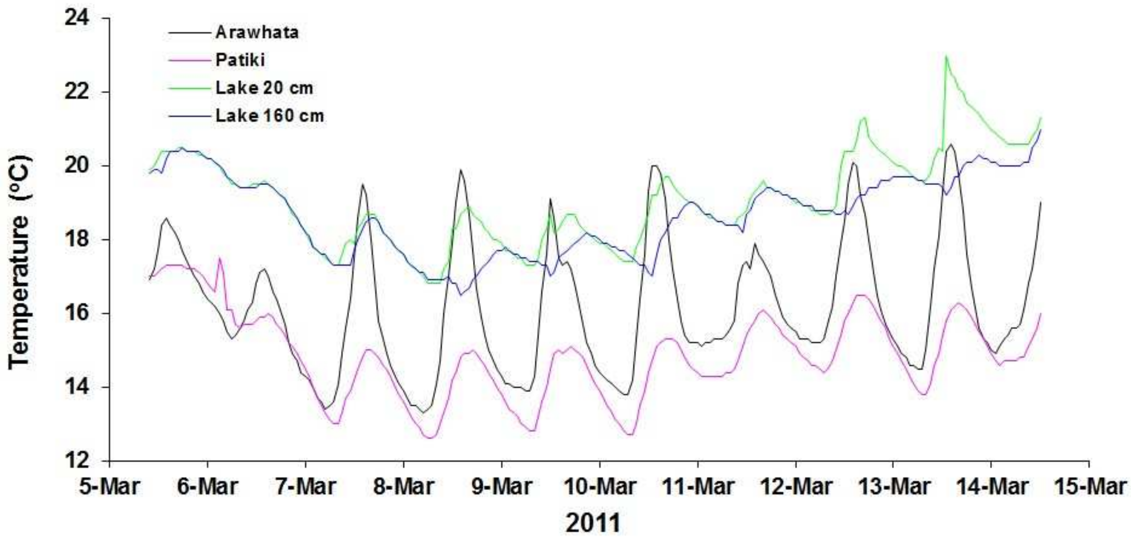

Figure 2-7: Diel temperature fluctuations. Lake Horowhenua and stream inflow temperatures rise and fall on a diel (day vs night) cycle. The high temperatures in the Arawhata stream demonstrate day-time heating on sunny days. The temperatures in the Patiki stream show the effect of shading. Water with a temperature above the lake temperature will float on top of the lake while water colder than the lake will move along the lake bed as it moves through the lake. Redrawn from Gibbs (2011).

Solution

This problem would be solved by shading of the lower 3 km of the Arawhata Stream and its lower tributary that enters from the west 0.5 km from Hokio Beach Road. Established shade would (1) control plant biomass and metabolism at a low level (through light limitation) preventing night-time anoxia driven by high plant biomass; and (2) cool the stream temperature during the day to below the lake temperature so that the inflow enters as an underflow of oxygenated water across the lake bed throughout the day during summer.

The Arawhata Stream currently has riparian trees along its south-eastern side for 1 km south of Hokio Beach Rd, but the north-western side lacks tall riparian vegetation (Figure 2-8). Consequently, the stream is unshaded resulting in high temperatures, high plant biomass/metabolism and low night-time oxygen.

Figure 2-8: Arawhata Stream from the Hokio Beach Road. A) View south and B) view north, showing the lack of shade in the lower reaches of the stream. Trees on the eastern side (A) offer no shade to the stream. [Photos 14/12/2012]

There is a need for adaptive management:

This action involves a trade-off between riparian shade reducing the dissolved oxygen and temperature of water entering the lake to reduce lake sediment P release, and shade reducing the likely in-stream uptake/transformation of nutrients in the lower Arawhata via in-stream plant uptake. The shading would aim to reduce the temperature and in-stream plant growth enough of produce a cool inflow of oxygenated water but to still allow low to moderate plant growth to benefit nutrient uptake.

Deciduous poplars are recommended for planting at 5 m spacings on the NW side of the stream, south of Hokio Beach Rd between the farm raceway and the stream. These (poplars) are recommended because they:

- grow quickly from poles
- are relatively inexpensive
- allow light, supporting modest plant growth, into the stream during winter and spring when the stream carries its higher nutrient load, and
- can be easily managed to manipulate shade.

A 5-m spaced planting should provide adequate shade while allowing for machinery access for drainage maintenance if necessary. Monitoring of the stream response to shade development, in terms of summertime diel dissolved oxygen, temperature and in-stream plant cover, will be needed to allow adaptive management of shade to optimise the shade level of these processes (by thinning/adding to the riparian vegetation) to benefit the lake.

Costs

Total $9,000 (excluding GST).

The cost of planting poplars along the north side of the Arawhata main-stem upstream (south) of Hokio Beach Rd and the two lower tributaries is estimated at up to $4000 (including sleeves on pole planted along the tributaries).

Native plantings are recommended for both sides of the 300 m of stream north of Hokio Beach Road connecting to, in keeping with the existing lake riparian plantings. This reach has existing fencing, with a narrow strip of land (1-2 m) between the fence and the north-western side stream and a wider (c. 5 m) fenced strip on the SW side. The cost of establishing natives in this area is estimated at $2500. A contingency cost of $2500 should be included to allow for unforeseen issues.

Native trees that could be used for this section of riparian planting would be the same range as suggested for the enhancement of the riparian buffer zone around the lake (Table 2-1).

2.5 Weed harvesting

Problem

The review of Lake Horowhenua (Gibbs 2011) identified that the summer bloom of cyanobacteria was triggered by the collapse of the lake weed beds onto the lake bed where they decomposed and smothered the sediment surface. The decomposition action consumed dissolved oxygen from the water at the sediment surface while the smothering action blocked reoxygenation from the overlying water. This resulted in a rapid release of soluble phosphate from the sediments, supporting the cyanobacteria bloom. This is problematic because, during the growth phase in spring, the lake weed completely removes the nitrate nitrogen from the lake water column. Simply eliminating the lake weed by spraying would leave high concentrations of nitrate in the lake water column to stimulate the growth of other non-cyanobacteria algal species to bloom proportions.

Solution

Weed harvesting to manage the lake weed for maximum nitrogen uptake and minimum phosphorus release.

Having weed in the lake is beneficial in terms of reducing nitrate concentrations in the water and providing lake bed protection from wind-wave suspension of sediment. Consequently, the timing of weed harvesting would be balanced between having the spring weed growth remove the maximum amount of nitrate into the plant biomass and harvesting and removing it from the lake before it collapsed onto the lake bed causing the phosphorus release.

The advantages of weed harvesting are that:

- the nitrogen and phosphorus assimilated into the plant tissue would be removed from the lake as a quantifiable nutrient reduction to the lake
- the management of the weed can be adapted to suit the conditions by changing the timing of harvesting and the cut height above the lake bed to provide areas that can reduce the effects of wave action
- the harvested weed can be composted with revenue from the sale of the compost used to offset the cost of harvesting, and
- there would be no need to use sprays or add foreign material to the lake.

The disadvantages of weed harvesting are that:

- the harvesting would need to be done each year as an on-going cost, and

- the weed harvester may not be available when required to manage the weed in Lake Horowhenua.

Because of the uncertainty of weed harvester availability when required, consideration should be given to purchasing a weed harvester. Preliminary investigations suggest that potentially suitable weed harvesters are available from China (Figure 2-9;Figure 2-10). Owning the weed harvester would provide an opportunity to manage lake weed in other HRC lakes by clearing access ways and bathing beaches, etc. The small weed harvesters are less than 3 m wide and could be transported by road between lakes, after suitable cleaning.

Figure 2-9: Weed harvester. Small weed harvester (left) is driven by paddle wheels with a cutting speed of 2 to 4 km/h – cutter assembly at front (left). It has a hold capacity of up to 10 t wet weed (depending on model). The unloading conveyer ramp at the back can off-load to a truck at the landing or into a transport barge (right) to allow it to continue working while the transport barge shuttles the weed to shore. Generic photo from web.

Figure 2-10:Weed harvester cutters. The cutter blades are about 2 m long on both sides and across the bottom with the cutter head able to be raised and lowered to adjust the cutting depth. The ramp behind the blades draws the cut weed into the hold of the harvester. This image shows a harvester without the paddle wheels attached, as would be needed for road transport. (Generic photo from the web).

Harvester efficiency

Information from the weed harvesting on the Te Arawa/Rotorua Lakes, where hornwort is a problem, indicates that between 2700 and 3400 tonnes wet weight could be removed in a 10 week period (i.e., 400 hours) This equates to a harvesting rate of 6.75 to 8.5 t hr^{-1}, the variability reflecting accessibility and weather effects.

Hornwort is a dense, free floating weed which drifts with the currents in the lake and can accumulate in large masses. In contrast, *Potamogeton crispus*, the lake weed in Lake Horowhenua, is a rooted macrophyte with tall stems extending to the surface in late spring and summer. It has sparse leaf distribution compared with hornwort and may produce about half the biomass per unit area. This would allow double the lake area to be harvested before unloading and thus reduce the time required to manage the weed. However, assuming a 10 week harvest period to prevent collapse and sediment P release, harvesting would need to begin in mid to late November.

A literature search indicates that the standing stock of *Potamogeton crispus* ranges from 15 to 43 g dry weight m^{-2} (Rogers & Breen 1980) with N and P contents of about 3% and 1.2% of dry weight, respectively. Based on the lake area of 3 km^2 these values represent nutrient content of the weed of up to 3.9 t N and 0.5 t P. At the maximum standing stock, the P content of the weed would be about 0.17 g m^{-2}, which is a substantial part of the legacy P load of 0.64 g P m^{-2} in the top 1 cm of sediment in the lake (Gibbs 2011). If all of the weed was harvested each year, this would result in a long term improvement in the lake water quality in a relatively short period time.

Weed nutritional value

Literature information for *Potamogeton* indicates that it is largely unpalatable to lambs (Linn et al. 1975) rendering it unsuitable as stock food. However, with the relatively high N and P nutrient content, it is suitable for compost and for mulching.

Cost

The basic cost of weed harvesting depends on the availability of a suitable weed harvester for hire or the purchase of a new harvester for HRC, and whether the harvested weed can be composted and the compost (or mulch) sold to offset harvesting costs. This composting may be contracted out to a private company or may be run by the lake owners under direction of the Domain Board.

A base daily rate for hireage of a New Zealand based weed cutter is between $2960 and $5160 per day. This excludes any disposal costs or positioning costs. A 400 hour contract is 50 days, giving an annual hire cost of between $148,000 and $258,000.

An alternative option to hireage is to purchase a weed cutter for HRC. A basic weed harvester new from China may cost between $50,000 and $200,000 depending on size. Second-hand machines are also available.

Operating costs (two people), excluding fuel, based on 400 hours operation would be between $40,000 and $60,000 pa assuming easy access to an off load area for transporting the cut weed away from the lake. No estimate has been made for transport or composting facilities.

2.6 Lake level management

Problem

In 1956, a weir was installed on the Hokio Stream outlet from Lake Horowhenua to hold a constant lake level as a geographical reference for the legal boundaries defining land ownership of and around the lake. That weir blocked free access of the diadromus fish population to the sea and turned the lake into a sediment trap. The weir is the main cause of the accelerated eutrophication of the lake because it eliminated the main natural cleansing process for the lake — flushing.

Before the weir was installed, the lake level rose and fell according to the seasonal patterns of rainfall. Sediment in the inflow streams passed through the lake aided by wind-induced stirring to reduce the amount of sediment retained in the lake. The average sediment accumulation rate (SAR) in the middle of the lake is estimated to have been in the order of 2 mm/y. After the weir was installed the SAR increased to about 10 mm/y and the maximum depth of the lake decreased from over 2 m in 1950 to about 1.6 m at present. From 1962 to 1987, sewage effluent from Levin was disposed of in the lake, enriching the sediments with the nutrients N and P. Decomposition processes in the sediments convert the particulate organic matter to inorganic forms of N and P, which are rapidly used by lake weed for growth. In mid- to late summer, when the lake is calm and the weed beds collapse, P is released into the water column supporting the growth of blue-green algae (cyanobacteria). These rapidly reach nuisance bloom proportions with wind drift scum accumulating on the eastern shores. These scums release toxins into the water, requiring the lake to be closed to the public.

Solution

Use water level control at the weir to enhance flushing by raising and lowering the lake level to (1) reverse the process of sedimentation, (2) mine the nutrients from the lake and (3) improve the native fishery.

To achieve this, the lake water level needs to be able to be raised by about 20 cm and lowered by at least 30 cm from the present fixed level at different times of the year, as follows:

Lower the lake level in winter to take advantage of periods of heavy rain, high flows and high winds. Low lake levels expose the near-shore sediments to increased wave action which can suspend fine sediment. With less water over them, the surface layers of the deeper sediments are also suspended in the water column along with nutrients from the pore-water. Heavy rain on the exposed lake bed further erodes the fine sediment carrying it out into the lake. The lake becomes highly turbid. High inflows flush the turbid water and nutrients out of the lake. The higher flows in the Hokio Stream carry the suspended solids to the estuary and the freshwater acts as an attractant to diadromus fish which run upstream in winter (August-September).

Raise the lake level from October through to mid-summer allowing the water to move into the marginal vegetation around the lake edge where whitebait spawn. High lake levels reduce suspension of the near-shore sediments and the deeper water sediment and pore-water suspension in the main body of the lake. The lake becomes clearer. Higher clarity enables weed growth to take up N from the lake water and enhances shag predation of pest fish which eat the zooplankton grazers. Deeper water provides weed-free water for boating during summer as well as an opportunity to harvest lake weed.

Return to normal lake level during late summer and autumn by periodically suddenly lowering the lip of the weir a few cm to draw floating algae out of the lake during any algal bloom event. This process will result in a lower lake level, ready for the winter sediment flushing part of the cycle.

This process will gradually remove the nutrient enriched sediment and reduce the occurrence of conditions that favour cyanobacteria blooms. There will be a range of other associated measures that would improve the efficacy of this strategy, the most important will be clearing the rushes and weeds that form a plant filter across the outlet to the lake to allow rapid outflow of sediment-laden water from the middle of the lake, rather than slow moving edge water which has lost much of its sediment load in the reed beds along the shoreline.

Practical considerations

A site visit on 14 December 2011 found that the weir was submerged due to backing up of the Hokio Stream and, consequently, was not functioning as intended (Figure 2-11 A). The high water level below the weir was attributed to choking of the Hokio Stream by fallen willows, branches and associated debris. Before the weir could become functional again, the Hokio Stream would need to be cleared to re-establish a natural flow with clear passage from the lake to the sea.

Clearance of obstructions in the Hokio Stream is also critically important for restoration of the fishery in Lake Horowhenua. Note that to reduce or eliminate bank erosion during this clearance process, 1) initially only the middle sections of fallen logs should be removed to keep the faster water away from the banks, 2) the clearance should be undertaken from seaward end working upstream, and 3) the clearance work should be done during the low flow period in autumn.

A key design principle behind flushing fine sediment (up to 0.1 mm size fraction) out of the lake is to maintain a water velocity of at least 5 cm s^{-1} through the outlet from the lake and over the weir (Hjulström 1939). Presently, riparian plants encroaching across the outlet channel from the lake reduce the channel width (Figure 2-11 B), which then opens out into a wider basin behind the weir structure. This configuration results in a sudden reduction in water which allows the heavier particles to settle out behind the weir — there is a substantial sediment build up behind the weir.

To allow the weir to function as described above to enhance flushing, the plant encroachment at the lake outlet would need to be removed and the weir would need to be redesigned. The redesign should maintain a constant channel width from the lake to the weir to reduce sediment accumulation behind the weir. This would require the width at the crest of the weir to be the same as the width of the channel at the lake outlet, or narrower.

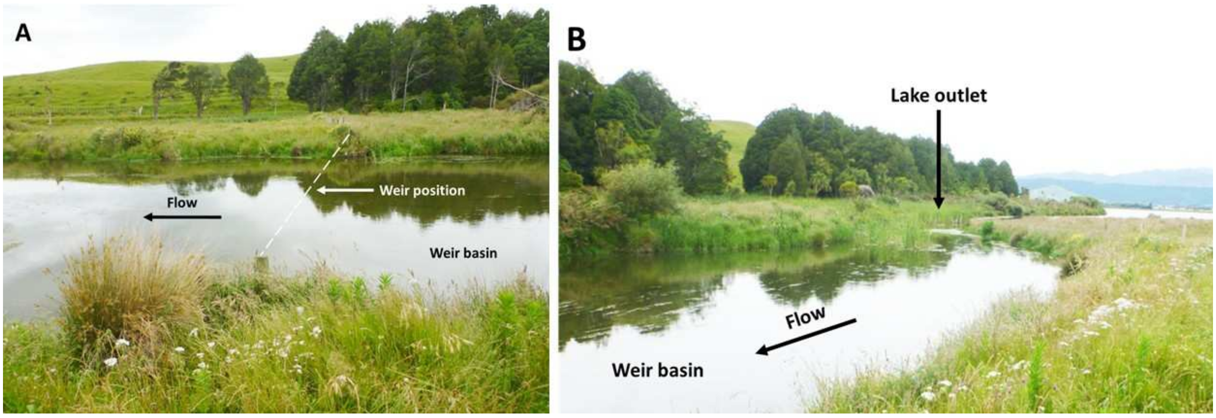

Figure 2-11:Weir Configuration. **A**) Weir basin showing the position and orientation of the weir (white broken line) which is submerged, and **B**) the outlet of the lake with encroaching riparian plants. [Photos 14/12/2011].

There are two options for this, either modify the existing weir or construct a new weir in the original out-flow channel. When the weir was built, a channel by-passing the natural outlet stream was built to allow the weir to be built on dry land. The out-flow water from the lake was then diverted through the by-pass channel to the weir and the original outlet channel was closed (Figure 2-12; Figure 2-13).

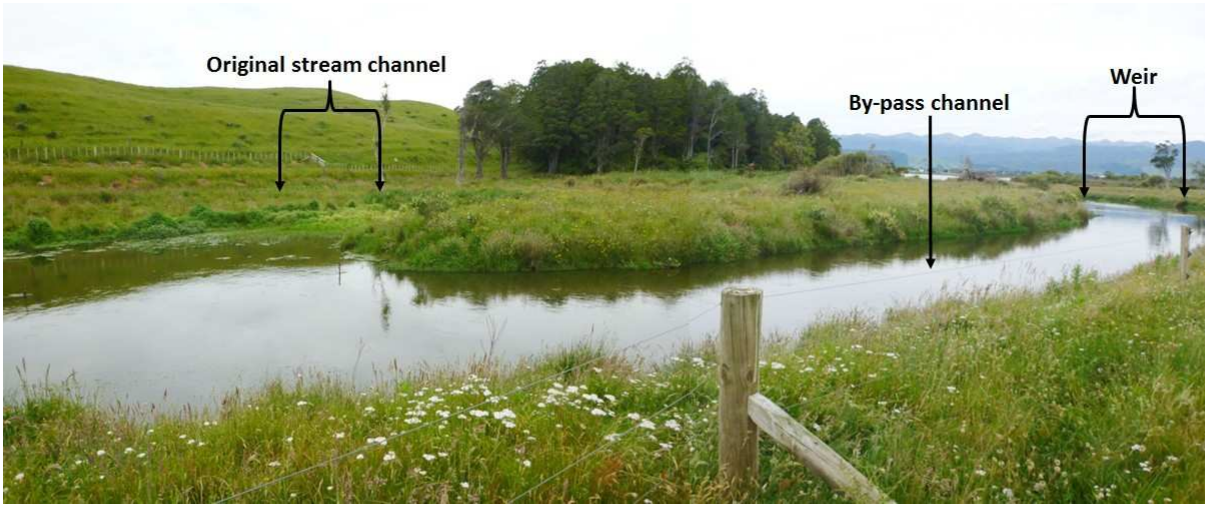

Figure 2-12:Hokio Stream at the confluence of the by-pass and original stream channels downstream from the weir. The original stream channel flowed on the left side of the photo (true right bank). [Photo 14/12/2011].

The work proposed would make use of the original channel to by-pass the weir during the modifications or would have the new control structure constructed in the original channel before re-connecting it in place of the existing weir. The work assumes that the blockages in the Hokio Stream have been removed before commencing the work.

To modify the existing weir, a moving gate structure would need to be installed in place of a section of the weir wall equivalent the width of the outlet from the lake or narrower. The rest of the weir would be raised to a level equal to the maximum desired level in Lake Horowhenua. The sediment accumulation behind the weir would be cleared to a width equal to the width of the weir and a depth of about 1 m.

This configuration would allow the lake level to be controlled below the maximum level while offering protection against flooding during heavy rainfall events.

Installation of a new control structure in the original outlet channel (Figure 2-13) would require the channel to be straightened. The control structure would use a moving gate system up to the width of the outlet from the lake or narrower. The original weir would be raised to a level equivalent to the maximum desired level in the lake to provide flood protection during heavy rainfall events.

Figure 2-13:Lake outlet and weir. The original stream channel is indicated with broken red lines. [Photo from Google Earth; 9/3/2011].

Weir gate design

There are many designs of weir gate but most either control water flowing over (over-shot or head gate) or under (discharge or sluice gate) the control element. Some offer both options in combination including the option to lift the whole gate out of the weir to allow maximum flow during peak flow conditions (Figure 2-14).

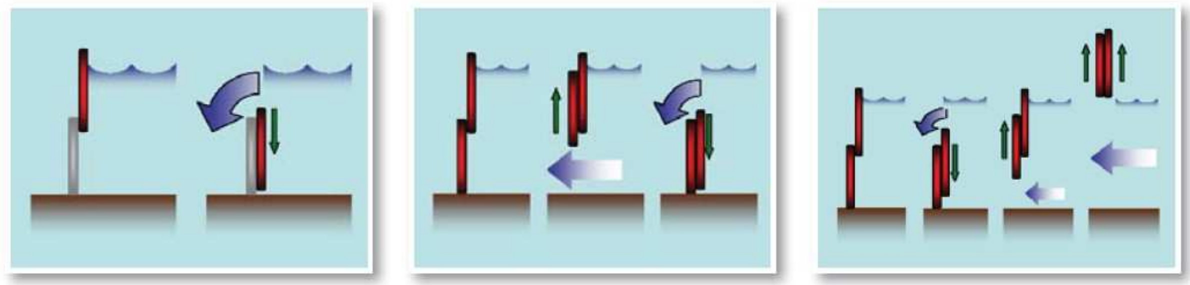

Figure 2-14:Basic weir gate design. (Left) fixed base downwards opening head gate, (centre) combination head and discharge gate with both elements able to move (right) combination head and discharge gate with an option to remove during flood events. (Generic diagram from the web).

Part of any weir gate design consideration is sediment accumulation behind the weir. While the downwards opening gate (Figure 2-14; left) offers good regulation of water level in the lake, the combination head and discharge gates (Figure 2-14; middle and right) offer a mechanism for clearing sediment from behind the weir before it can accumulate, i.e., the sluice gate principle. The sluice gate design, however, is known to be a hazard to swimmers as they can be held against the opening below the water and drown (e.g., NZ Herald 20 January 2012: Appendix A). There should be trash bars before the sluice gate to provide an escape mechanism for the swimmer and would-be rescuers.

The downwards opening gate is equivalent to a drop log gate but provides a finer level control. Drop logs can be manipulated by tractor and the downwards opening gate requires a worm drive (manual or electric) to move the gate against the pressure of the water behind the weir. One gate design, the drum gate, uses that water pressure to open or close the gate (Figure 2-15). This design may have less fouling problems that the sliding gates. The spill side of the weir can be a hazard as a 'hydraulic" or undercurrent can develop at the base of the structure, trapping and drowning the unwary. The solution is to include an energy dissipation design in the toe of the spillway to prevent a deep pool forming.

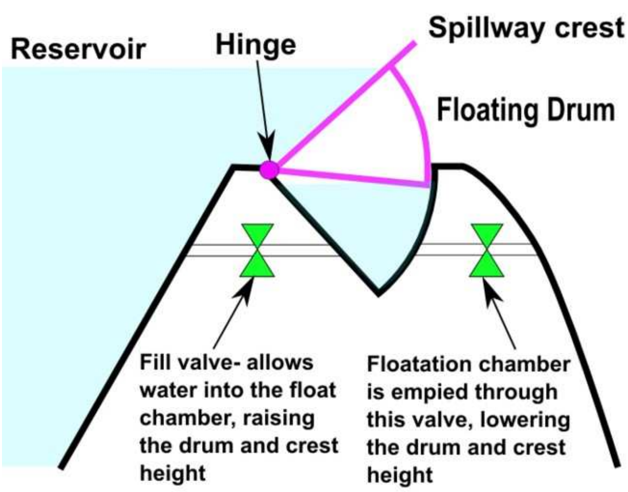

Figure 2-15:Floating drum weir gate. The base of the weir is set to the minimum lake level and the floating drum is designed to control the water level in a finite range. (Schematic diagram from Wikipedia http://en.wikipedia.org/wiki/Floodgate January 2012).

Cost:

Costs are divided between capital expenditure and running costs. The main costs will be capital expenditure associated with the modification of the weir to allow lake level manipulation. This will be a one-off cost but, as it is an engineering solution, it should be costed by an engineer. A guestimate would be in the range of up to $200,000 to modify the existing weir and dredge the channel back into the lake, or up to more than $1 million to reinstate the original outlet channel with a new control structure.

The cost associated with obtaining the amendment to the ROLD Act 1956 to enable the lake levels to be managed may be up to $50,000 in legal fees.

Once installed, the running costs (operation and maintenance of plant) are likely to be in the order of $5,000 to $10,000 per year.

2.7 Enhanced predation (top-down)

Problem

Perch are having a negative impact on the water quality and native fish populations of Lake Horowhenua. The lake supports a large population of perch, ranging from juveniles through to large individuals (Gibbs 2011). Perch are opportunistic and predatory fish, which change their feeding habitats as they age.

When young, perch graze on zooplankton. Since zooplankton graze on algae and can effectively control phytoplankton (algal) biomass, this unbalances the relationship between zooplankton and phytoplankton, allowing the phytoplankton population to increase largely unchecked, causing algal blooms and consequent impacts on water quality and recreational use of the lake. As they age, perch switch to larger prey, namely native fish and juvenile perch although these may be protected by the low water clarity. Perch will be the top predator in the lake and will be suppressing native fish populations through predation.

Solution

The solution proposed for Lake Horowhenua is to increase the level of predation of perch within the lake by improving conditions for shags. This will be done in two ways:

- Firstly, by improving the clarity of the lake to increase hunting opportunities for shags. This will be done by harvesting the weed, and reducing erosion in summer through raising the lake level – both are covered in previous action summaries in this report.
- Secondly, provide roosting structures for shags. These are simple structures, comprising two uprights and a flat cross beam upon which shags can roost, rest, dry out, or search for prey. The structures would be placed around the perimeter of the lake just back from the lake edge.

The idea is that the shags will prey on the middle to larger sized perch, and with the increased clarity, the remaining middle to larger sized perch would begin to preferentially predate on small perch. This preferential predation would occur because perch are schooling fish when young and are active during the day and in open water, unlike native fish which are secretive and mostly active at night.

With the predation by shags and larger perch, the overall perch population is expected to decrease, resulting in improved water quality (as zooplankton will be in sufficient numbers to graze the phytoplankton) and native fish populations. This is expected to be a positive feed-back approach with the increased zooplankton grazing pressure maintaining a higher water clarity which will enhance predation of the small perch and reduce the predation pressure on the zooplankton (Figure 2-16).

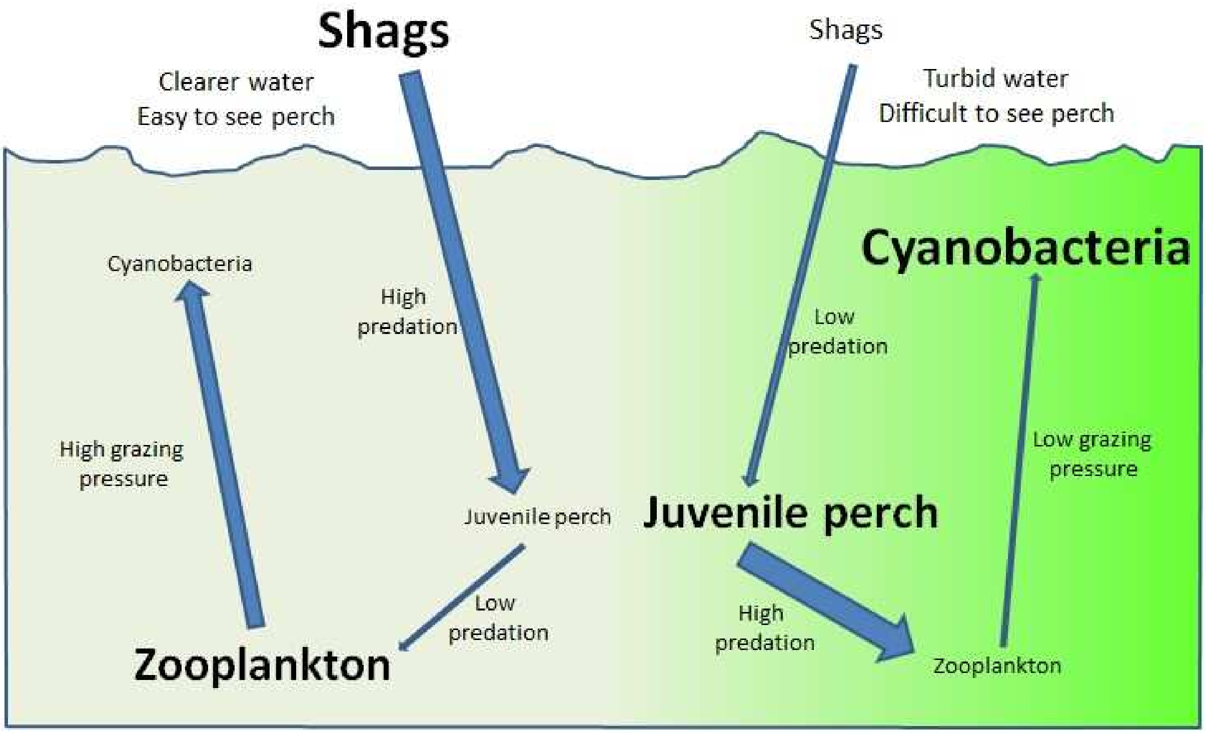

Figure 2-16:Top-down predation. Simplified food web: left side with increased numbers of shags reducing juvenile perch populations allowing zooplankton to increase in numbers to reduce the algal biomass, right side has limited numbers of shags allowing high juvenile perch numbers to reduce the zooplankton population and increase the algal biomass.

Costs

Each roosting structure is estimated to cost $600 dollars to install in terms of materials, labour, transport, and construction. This cost would increase if cultural elements (e.g., carving) were incorporated into their design to reflect the significance of the site to the owners.

The aim should be to install 10 of these structures per year for two years. Additional structures can be installed at a later date if there is a need.

Total cost of the roost would therefore be about $6000 per year for two years. Subsequent maintenance would be minimal and on a case by case basis as repairs were needed. The cost of this project could be shared between a number of partners and it could become a community/ / iwi project.

2.8 Fish pass

Problem

The weir located 800 m upstream of the Moutere Rd bridge has controlled the level of Lake Horowhenua since 1956, to define the legal boundaries of the lake. This weir currently creates a drop of approximately 1 m under normal flows, which is impassable to several species of diadromus fish that would otherwise use the lake as part of their life cycle. Eels are able to travel overland on wet grass and elvers and climbing galaxiids can climb wet surfaces, so the movements of these species are probably not impeded significantly by the weir. However, inanga whitebait, grey mullet, smelt and flounder are swimming fish that are expected to be unable to pass the 1 m drop at the weir and so have been lost from the lake fishery.

Solution

Install a fish pass to allow fish to move over the weir and into the lake (e.g., Figure 2-17).

It is anticipated that, at some time in the future, the weir will allow for a variable lake height, and the planned operating regime is to lower the lake level in winter to spring and then increase the lake level during late spring and summer. As this variation of lake level will coincide with the main upstream fish migration period (spring/summer), the flow over the weir is likely to vary. Consequently, it is recommend installing the fish pass at the margin of Hokio Stream rather than directly integrating it into the weir. As the weir will also be flushing water and sediment from the lake during winter, designing a fish pass that is not incorporated into the spillway of the weir is desirable as it will reduce damage to the pass, but still cater for fish passage during high flow events.

Option one - baffled ramp: Passage for species such as smelt and inanga can easily be achieved by utilising a baffled ramp from the lake to the stream margin below. No experimental work on the passage requirements for mullet and flounder have been undertaken to date, and the morphology and behaviour of these species will require different hydraulic conditions to those promoting passage of small bodied fish such as inanga and smelt. It is anticipated that the ramp design can be modified to promote mullet passage, however it is unlikely that flounder passage can be catered for using this style of fish pass. A baffled ramp fish pass will also provide passage for climbing galaxiids and elvers.

A channel to control head and flow down the ramp will be created so that the fish pass will be compatible with the planned variable height operation of the lake over a range of about 0.3 m.

Option two – nature-like channel: Based on the behaviour of flounder and their morphology in being a dorsoventrally flattened fish, it is likely that creating a nature-like channel (a low gradient meandering channel) will be the best option for ensure successful passage to and from the lake. This type of fish pass will also promote successful passage of all target fish species, but it will also need a flow control device to ensure a minimum flow is provided over the full range of anticipated lake heights.

Costs:

The design, consenting and installation of each style of fish pass are estimated to be:

Option one - baffled ramp: up to $35,000 dependent upon site characteristics and logistics.

Option two – nature-like channel: up to $80,000.

The on-going maintenance costs of both fish passes are expected to be minor and incorporated into site visits during regular flow and water quality monitoring of the outlet by Horizons Regional Council Staff.

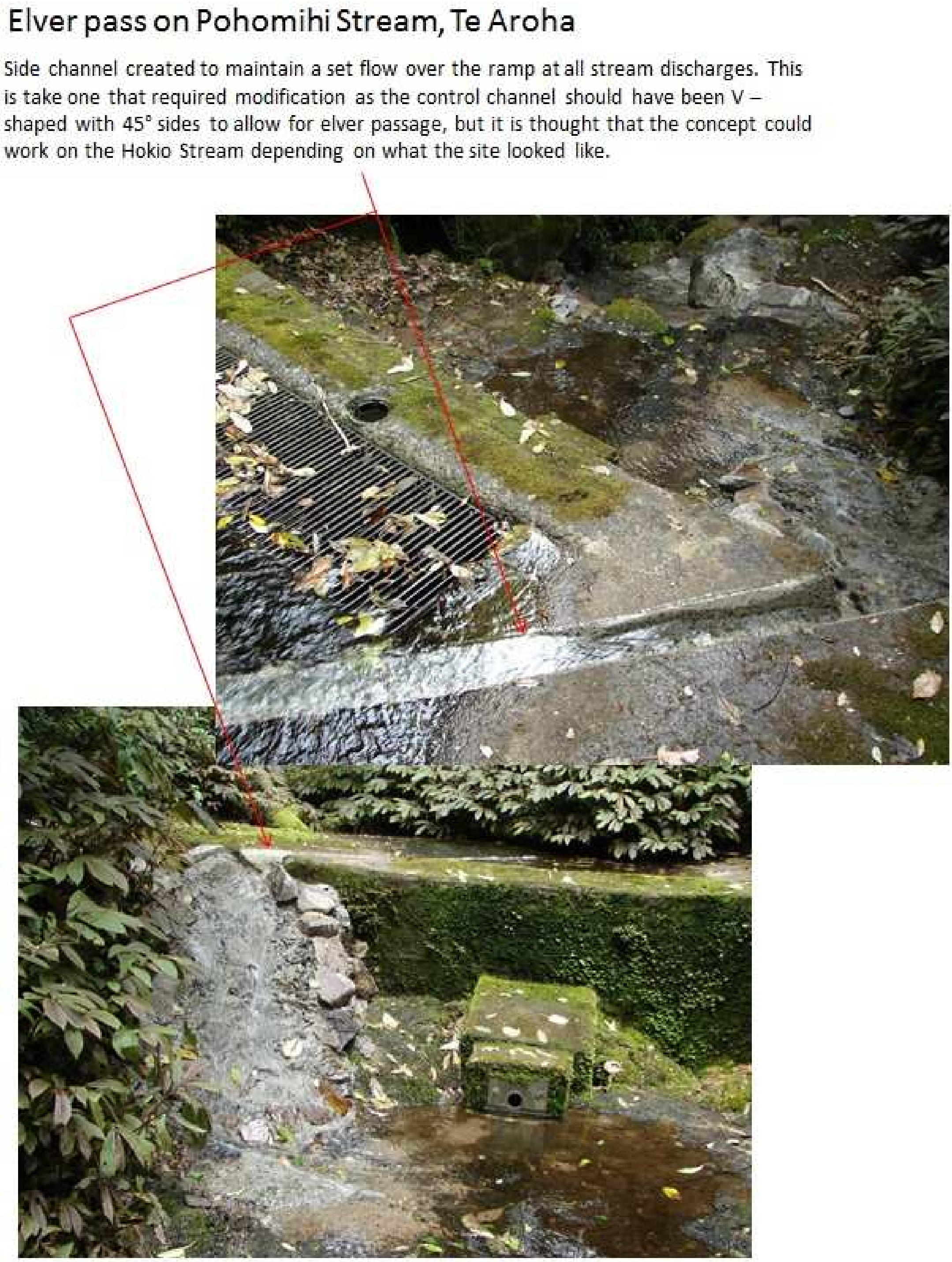

Figure 2-17:Example of a fish pass at Te Aroha. (Text and Photos: Cindy Baker, NIWA)

2.9 Boat treatment and weed containment

Problem

Lake Horowhenua is used for recreational boating (rowing and sailing), and there are also commercial eel fishermen operating in the area. With the movement of boats on and off the lake, and in some cases to other waterways, there is potential for aquatic weeds to be introduced to the lake from elsewhere, or spread from the lake to other sites on boat trailers (Figure 2-18). Exotic weed caught in the mesh of nets is also a potential vector for introducing new aquatic weed species into the lake, although commercial eel fishermen will be aware of this issue.

Figure 2-18:Weed can be transported between lakes on boat trailers. Hornwort and filamentous algae festoon a boat trailer at Lake Rotoehu. Even a small piece of Hornwort will grow if left on the trailer when it launches the boat in the next lake.

The "danger" to the lake from the introduction of exotic weeds such as *Egeria densa* and/or hornwort is that they have "aggressive" growth habits which would irreversibly change the water quality and character of Lake Horowhenua. *Egeria densa* has a boom and bust growth cycle, such that it spreads across the lake as a surface-to-sediment biomass, dramatically reducing the open water available for contact recreation. The biomass in the lake becomes dominated by weed. At this time (boom phase) the open water will be relatively clear as the *Egeria* has assimilated all of the nutrient inputs from the catchment and sediment release, and suppressed sediment suspension by wave action. The bust phase sees the weed beds collapse and release the stored nutrients as they decompose driving a massive algal bloom. The decomposing weed causes oxygen depletion which, in turn causes sediment release of nutrients, especially phosphorus, which favours the growth of toxic cyanobacteria blooms. The shading caused by the algae inhibit the growth of weed and the lake becomes algal (phytoplankton) dominated, such that the water column always has a high algal content and there is no weed to reduce sediment suspension by wave induced currents. If fragments of the *Egeria* survive, the cycle will repeat. The classic example of the effect of this weed is Lake Omapere.

Hornwort is a non-rooted weed that drifts around the lake with wind driven currents. As with *Egeria densa*, hornwort assimilates nutrients from the water column for growth. If it lies on the lake bed it causes local areas of anoxia, which results in the release of phosphorus and the concomitant growth of cyanobacteria blooms. When it floats to the surface, it forms drifting islands of weed, which inhibit the use of the lake. When the floating mats drift to shore they rot, causing foul odours for local residents, and release nutrients that drive the algal blooms. Classic examples of the effect of this weed are Lake Rotoehu, where a number a measures are being trialled to combat the weed, and several of the Auckland Council coastal dune lakes on the west coast.

Solution

It is proposed to construct a wash-down facility for boats at the domain launching area so they can be washed down prior to entering the lake, and before they leave the vicinity of the lake after being on the lake. Such precautions are not required for those boats that are stored at the lake and/or are used nowhere else. But all boats that are used elsewhere should follow this procedure before going on the lake.

There are two ways to 'sterilise' a boat – complete wash-down, or chemical treatment. Given that aquatic weeds, especially *Egeria densa* and hornwort, rather than algae are the key threat to the lake, wash-down is the preferred method. This requires two things:

- First there needs to be a wash-down area where wash water cannot enter the lake or other water bodies via overland flow, drains, or the stormwater system.
- The second is a means of washing down the boats e.g., a weed rake and a water-blaster. In most instances weed will be caught on the boat trailer and most will be able to be removed with a purpose built weed rake. The rest will need a water blaster to remove.

It is proposed to build a wash-down facility involving a hard (tarsealed) drive on/off apron, and a large sump area filled with gravel and covered with permeable rubber matting. Wash water and vegetative material would pass through the rubber matting into the sump where it would eventually drain to groundwater, or could be diverted into a spill-drain system. This facility would be located within the Lake Domain at a convenient location. A water supply and potentially a power supply would need to be provided at the facility. A water-blaster would be provided to the yacht and/or rowing club and anytime they held an event, they would set up the blaster at the facility and ensure boat operators followed the clean-up protocol.

Costs

The estimated cost of the facility would be $6000 to construct the facility, which would cover labour, construction, materials, and rerouting of services. There would be an additional cost of $1000 to cover purchase of up to two water-blasters.

The total cost of making the facility operational would therefore be $8000. This project could be built with funding shared between partners including Horizons Regional Council, and Horowhenua DC/Domain Board/yacht club/rowing club. The yacht/rowing clubs would be responsible for security and maintenance of the water-blasters, and Horowhenua DC would cover the cost of power/water.

2.10 Enhanced monitoring

Problem

The water quality data from Lake Horowhenua is at best “patchy”, with significant gaps in the data that make it difficult to identify trends that reflect changes in water quality. There is no recent nutrient budget to assess whether more nutrients are leaving than are entering or vica versa. The last published nutrient budget for Lake Horowhenua was for the period 1988/89 (Gibbs & White 1994). Although lake data have been collected periodically since the 1970s, there is no contiguous data set that can be used to differentiate between “natural variability”, “seasonal cycles” or “impacts” from anthropogenic influences or climatic changes. At present there is no state of the environment (SOE) monitoring of the lake to allow comparison of the lake condition with other lakes in New Zealand (last measurement was 2008). Periodic spot measurements can give an indication of the lake condition on the day it was sampled and these can be misleading without a strong database to support their use/ interpretation.

Understanding how a lake works requires good quality time-series data on water quality changes in the lake and a nutrient budget. With this set of proposed actions to restore the lake, water quality monitoring data are needed to assess how the lake responds to the proposed management strategies and the effectiveness of the actions taken. Monitoring data is also needed to enable adaptive management to get the best out of the actions being implemented.

Solution

Establish a monitoring programme specifically designed for the lake that will provide the database for informed decisions for effective management and restoration of the lake. This monitoring programme must include the stream inflows and the Hokio Stream outflow to allow the construction of a nutrient budget for the lake.

The Lake Horowhenua restoration project will implement new activities and significantly expand the scope of existing activities around the lake. The new activities are designed to significantly increase the rate of restoration of the lake that has been impeded by legacy effects of past sewage discharge, lake level management and land use intensification. New livestock exclusion fencing and vegetated riparian buffer zones along streams will eliminate direct animal inputs to surface water and reduce nutrient and sediment loads to the lake. Diversion of key diffuse inputs of urban/rural contaminants in the Queen Street Drain will remove a significant portion of the phosphorus load into the lake. Farm environmental plans, targeting areas of intensive agriculture and horticulture, will result in new initiatives to reduce nutrient and sediment inputs to the lake (e.g., through nutrient management plans, targeted buffer strips, silt traps, livestock exclusion and changes in tillage practice in key source areas).

New actions will be undertaken to effectively mine the stored sediment and phosphorus in the lake bed through lake level manipulation and weed harvesting. Expansion of existing riparian buffer zones will enhance interception of nutrients at lake margins.

Lake monitoring

The review of Lake Horowhenua report (Gibbs 2011) included a lake monitoring programme to meet the needs of the restoration project. At the heart of the monitoring programme was a strategic monitoring programme to evaluate the water quality in the lake over meaningful time frames (Table 2-2). Details can be found in the review report. In addition to the parameters listed in the table, particulate carbon, nitrogen and phosphorus (PC, PN and PP) should also be measured on each occasion.

Strategic Monitoring Programme for Lake Horowhenua														
Monitoring equipment														
DO / Temperature	Dissolved oxygen / temperature probe on a cable													
Secchi disc	Weighted black and white quartered 20 cm disc on soft tape measure													
Water sampler	Composite of 3 integrated tube samples from each of 3 traditional monitoring sites (9 tube samples)													
Zooplankton net	Composite net haul with 63μm mesh on cod end - OPTIONAL													
Sampling time to be around 10 am or around 4 hours after sunrise														
Parameter	**Sample Type**	**Units**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
On site observations														
Start and finish time	Date and time	yyyy:mm:dd hh:mm												
Lake level	Staff guage	m												
wind condition	estimate	text												
cloud cover	estimate	%												
Algal bloom / scum	Shoreline observation	Yes/No												
In lake measurements														
Temperature	Instrument profile	ºC												
Dissolved oxygen	Instrument profile	$g\ m^{-3}$												
Clarity	Secchi depth	m												
Depth	Tape measure	m												
Laboratory measurements														
Algal species	Water sample	cell counts, biovolume												
Chlorophyll *a*	Water sample	$mg\ m^{-3}$												
SS / VSS	Water sample	$g\ m^{-3}$												
Turbidity	Water sample	NTU												
E. coli	Water sample	MPN / 100 ml												
Conductivity @ 25ºC	Water sample	$\mu S\ cm^{-1}$												
pH	Water sample	pH												
DRP	Water sample	$mg\ m^{-3}$												
TP	Water sample	$mg\ m^{-3}$												
NH_4-N	Water sample	$mg\ m^{-3}$												
NO_3-N	Water sample	$mg\ m^{-3}$												
TN	Water sample	$mg\ m^{-3}$												
Cyanobacteria toxins*	Water sample	$mg\ m^{-3}$												
			TLI parameters				4 times per year				Additional for 6 times per year			

Table 2-2: Strategic monitoring programme for Lake Horowhenua. (*Cyanobacteria toxins need to be measured in the lake water and in the edge-water scums.) Reproduced from Gibbs (2011).

Additional monitoring strategies could include the use of a lake Buoy, with a met station installed on the Yacht Club. Lake buoys have been installed in most of the Te Arawa/Rotorua lakes and provide real-time information on the state of the lakes. For example it could measure: temperature for identifying stratification, dissolved oxygen, and turbidity (OBS turbidimeter) to define what winds/depths result in resuspension and stratification, and when cyanobacteria scums could accumulate on shore. The buoy could include a Sonde that measures algal biomass as chlorophyll *a* and cyanobacteria content from the phycocyanin content.

Stream monitoring

A nutrient budget is required to determine whether catchment nutrients are being stored in the lake or being exported from the lake, as a measure of the restoration process and its progress. The nutrient budget is constructed from stream nutrient and flow data on the inflows relative to the outflows. A sampling and gauging station needs to be established on each inflow and on the Hokio Stream outflow from the lake. The parameters measured need to be the same as for the lake with an additional parameter for flow, which should be measured on each sampling occasion.

Costs

Capital cost of the buoy is likely to be around $35K (estimate only) and the telemetered met station could be in the order of $10K.

Analytical costs for lake samples are estimated to be around $1150 per sampling visit. The ideal sampling frequency would be monthly except during the 4-month period from December to March at 2-weekly intervals. That is 16 sampling visits costing $18,400 pa.

Stream gauging and monitoring costs are estimated to be $3000 per sampling — 16 sampling visits would cost around $48,000 pa.

2.11 Public education – lake report cards

Problem

Often, public perceptions of a degraded lake are that it is problem but not “their” problem. Because the changes have been insidious, the degradation process has not been linked back to the source. Consequently, there is a lack of willingness to “take ownership” of the problem. The farming/agricultural community have a problem connecting their action today that affects the groundwater quality, if it has no immediate effect on the water quality of the lake. As there is presently no monitoring programme to show the linkage, there is little incentive and often strong resistance to change the way things are done for no apparent benefit.

Nutrient loads do not just come from the farming community. Urban gardeners are known to be over generous when feeding their gardens and the excess fertilizer applied will leach into the groundwater or be washed off into the stormwater system.

Solution

Public education programmes, including “report cards” to establish the linkages and get community support for the overall restoration of the lake.

Based on groundwater hydrology calculations (Gibbs 2011), the flow time for groundwater to reach the lake from much of the catchment is around 6 months. Any nutrients lost from farm or home gardens in spring will affect the lake in autumn – when the lake develops a nuisance cyanobacteria bloom.

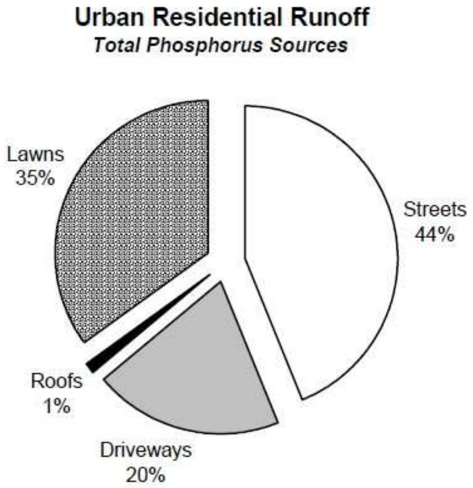

Figure 2-19:Urban sources of phosphorus. Proportional contributions of phosphorus to stormwater in the urban environment. (Barten & Parks 1999).

About 80% of the phosphorus entering a lake comes in the form of particulate matter with fine sediment carrying more phosphorus than the coarser grains (Figure 1-2). Literature assessments of urban contributions of phosphorus to a lake suggest that a simple thing like mowing the lawn without the catcher could adversely impact on the lake via leaf material entering the stormwater system. Keeping the streets clean by street sweeping is often used as a method for reducing fine dirt and organic matter inputs to lake overseas. Fertilizing lawns is prohibited in some states of the USA because of phosphorus runoff into the stormwater (Figure 2-19).

While information such as displayed in Figure 2-19 may help identify the issues, the use of report cards (just like the end of year school report cards) for the lake restoration measures may be more useful in sustaining public interest — connecting with the public and getting community “buy-in”. The report card is also a way of managing public expectations on the rate of recovery and the level to which the lake is likely to recover.

The concept of public report cards is relatively new to New Zealand but they are referred to by the Ministry for the Environment as environmental indicators to report on lake water quality and to measure changes in the nutrient (trophic) status of lakes. The data they use comes from SOE monitoring programmes. The most common indicator is the TLI (Table 1-1) and can be shown on the report card for Lake Horowhenua as a time-series of just the TLI values or the component parameters phosphorus, nitrogen, algal biomass (chlorophyll *a*) and clarity (Secchi depth) (Figure 2-20). Other information could also be included on the annual report card such as the amount of weed removed from the lake, the number of days the lake was closed due to cyanobacteria blooms, the catch rate of eels, the number geese and / or swans on the lake by month during the year, the number of shags, etc.

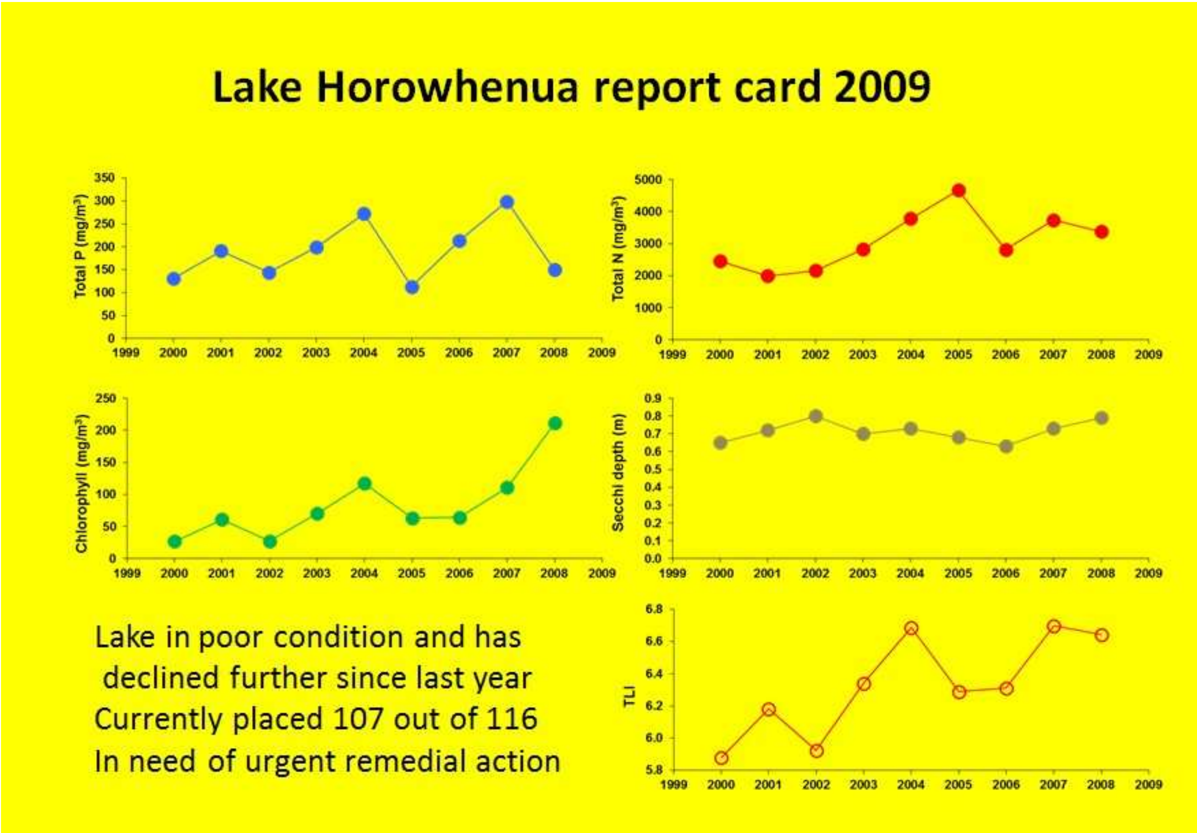

Figure 2-20:A report card might look like this. It could have more or less information. It would include the full contact details of the provider and could have information on where to view the original data. This is real data for Lake Horowhenua.

Examples of freshwater report cards being used to inform the public can be found on the Auckland Council site:
http://www.knowledgeauckland.org.nz/home/aklcouncil/aklcouncil_home.cfm

Apart from nutrients, other public education issues include informing well-meaning people not to empty their aquarium or goldfish bowls into a stream or a lake to “give the fish or plants a good home”.

Cost

The majority of the cost associated with preparing the report card would come under the monitoring programme. It would require consultation meetings with the community to introduce it and should have a public release of the report card each year to show how the restoration programme is working. Estimated costs $5,000 to $15,000 depending on the number of consultation meetings and the cost of printing.

3 Acknowledgements

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Appendix A Hazard associated with bottom opening weirs

New Zealand Herald 20 January 2012

Teen drowns when caught against river gate

A young woman who drowned at a popular Canterbury swimming spot is thought to have been pinned against a gateway by fast-flowing water.

The 18-year-old was swimming with friends in an irrigation waterway in the Waimakariri River about 1.30pm on Wednesday when she became trapped against the gateway, which feeds a water storage pond.

Selwyn District Council chief executive Paul Davey said her friends tried to save her but the current was too strong.

A council contractor arrived in about 15 minutes and opened the gate to release her body, which was recovered downstream.

Mr Davey said the waterway, which is near Kirwee in the Selwyn district, was considered safe and had been used by swimmers for many years.

The young woman's friends tried to save her but the flow pushed her against the gate on the Waimakariri River.

"However, like any river there are significant flow variations and at times of higher flow things can get a lot different."

The council was considering what to do to prevent deaths.

"We've got a problem with warning signs because when we put them up they get vandalised because it's a highly trafficked area and a very popular recreational site, so we're thinking about whether we need to put up more robust signage that will withstand the rigours of vandalism.

"We can't stop people from swimming in rivers. What we need to do is just to show them the risk of rivers in higher flow because they're a much more dangerous beast than when they're flowing normally."

There was already a warning sign about 100 metres from where the young woman drowned, he said.

Council engineers were looking at whether there needed to be structural alterations to the waterway.

"We've also got to remember that this is an important economic waterway for wider Canterbury and we've got to make sure that we don't limit our ability to service the farmers who rely heavily on this water source."

But it was important to make sure no other swimmers drowned. — *APNZ*

NZ Herald 20 Jan 2012

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