Containment of aquatic pest plants in the upper Whanganui and Waikato catchments

Lake Te Whaiau weir

NIWA Client Report: HAM2008-013
January 2008

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Executive Summary

NIWA was contracted to:

- Delimit and describe the current status of invasive aquatic pest species in the area of the upper Whanganui River.
- Assess the risk of dispersal of pest plants from Lakes Rotoaira, Otamangakau, and Te Whaiau, (particularly to the Whanganui River) and assess potential impacts.
- Advise on a strategy to limit chances of dispersal including monitoring requirements for early detection and control methodologies for current and potential infestations.

This work was requested by Horizons Regional Council and funded from an Envirolink grant through the Foundation for Science, Research and Technology. The area in the vicinity of the upper Whanganui River was delimited for invasive submerged aquatic weeds on the 15^{th} and 16^{th} January 2008. Horizons Regional Pest Plant Management Strategy (RPPMS) categorises lagarosiphon and hornwort as pest plant species with a management objective of 'containment'. These species are also listed on the National Plant Pest Accord (NPPA) banning them from sale and distribution. Elodea is invasive, but is so widespread, it is not subject to any management under RPPMS or NPPA and is a lesser problem than lagarosiphon or hornwort. Lake Rotoaira had extensive areas of hornwort and lagarosiphon with some elodea. Lakes Otamangakau and Te Whaiau had mostly lagarosiphon with elodea present but no hornwort. The upper Whanganui River and other headwater streams had no aquatic weeds.

Lagarosiphon and elodea have regularly been discharged into the Whanganui River catchment for years with discharges from Lakes Te Whaiau and Otamangakau. Although the Whanganui River has a highly valued status, the upper river and headwater streams are not considered to be at risk from invasive submerged aquatic pests, as the river has very limited habitat suitable for these species, due to irregular high flows and rocky substrates. Elodea was present over $<1,000 m^2$ at the Piriaka hydro impoundment on the Whanganui River near Taumarunui, the Ongarue River near the Ongarue township, in the Ongarue / Whanganui River confluence ($<5\ m^2$) where substrate and velocities permit. At Piriaka further weed growth is possible and other species such as hornwort and lagarosiphon could establish there but would not be of greater nuisance than elodea. Elodea may be enhancing habitat for trout in this area. The rest of the river is not suitable habitat for submerged aquatic weeds, except possibly the lower Whanganui River within 10 km of Wanganui, where the river widens and flows are less. In this area hornwort and egeria would be more competitive than lagarosiphon or elodea as the water is very turbid, however, it so turbid in fact that in combination with water level fluctuations weeds are most unlikely to grow.

Hornwort is ranked as New Zealand's worst aquatic weed and was widespread in Lake Rotoaira, where it has proven to be a major problem. This plant could easily be transferred to Lakes Otamangakau and Te Whaiau. The most likely means of transfer would be by introducing a small fragment with a boat / trailer moved from Lake Rotoaira or other source (such as Lake Taupo,

Waikato River or Rotorua Lakes). Hornwort poses a considerable risk to Lakes Otamangakau and Te Whaiau as it could potentially become surface reaching over much of these shallow lakes, interfering with boating and fishing and it could cause blockages in Wairehu Canal at the rotating screen.

With high boat usage on Lake Otamangakau it is inevitable hornwort will be introduced to this lake in the near future unless effective controls are put in place. Options for preventing introduction of hornwort are discussed. The recommended option to minimise the risk of transfer is to *prevent trailer access to the lake; ban the use of anchors and discharge of bilge water* within the lakes, and *place signage* warning of the consequences of hornwort introduction and how it can be avoided. Use of a containment boom (with netting to the lake floor) and a gate for boat passage from the boat ramp(s), and closing off any other area that might otherwise be used for boat access, could still allow motorised boat access and provide a high chance of containment upon introduction. It would also offer a higher likelihood of early detection when combined with proposed surveillance.

Genesis Energy already has adequate protocols in place to prevent their activities causing aquatic pest transfers in the area.

A regular surveillance programme (snorkel inspections of boat ramp areas December and April) could detect a hornwort invasion at an early stage. However, this has merit only if an effective response plan is pre-prepared and able to be implemented immediately and only if there is a realistic chance of success. An effective response would require rapid delimitation of the infestation, followed by treatment of the whole infested area with either diquat (treating the total water column to 2 mgL^{-1}) or endothall (treating the total water column to 5 mgL^{-1}). All necessary approvals (consents, possibly ERMA permission, and wider community consultation) would need to be obtained and in place prior to detecting hornwort to enable an early response to have *any* chance of success. Preventing the introduction of hornwort is far easier than attempting to control it once introduced as eradication would probably be an impractical option.

If hornwort became widespread in Lakes Otamanagakau and Te Whaiau the only practical way to control it would be to use the aquatic herbicide diquat. A December application annually targeting areas of nuisance would prevent surface reaching growths. Details of diquat and endothall (the two herbicides registered in NZ) are provided.

Recommendation: minimise the risk of transferring hornwort to Lakes Otamangakau and Te Whaiau by *preventing trailer access to the lakes (or restricting it to netted areas with boat gate); banning the use of anchors and discharge of bilge water; placing signage* explaining the consequences of hornwort introduction to the fishery and boating, and outlining how this could be avoided.

1. Introduction

The aquatic pest plant species lagarosiphon (*Lagarosiphon major*) and hornwort (*Ceratophyllum demersum*) (Fig. 1), are known to be present in water bodies near the headwaters of the Whanganui River. Horizons Regional Pest Plant Management Strategy (RPPMS) (Horizons, 2007) categorises lagarosiphon and hornwort as pest plant species with a management objective of 'containment'. The Strategy aims to prevent spread from current sites of infestation, with a particular focus on protecting waterways of Regional Significance such as the Whanganui River.

NIWA was contracted to:

- Delimit and describe the current status of invasive aquatic pest species in the area of the upper Whanganui River.
- Assess the risk of dispersal of pest plants from Lakes Rotoaira, Otamangakau, and Te Whaiau, (particularly to the Whanganui River) and assess potential impacts.
- Advise on a strategy to limit chances of dispersal including monitoring requirements for early detection and control methodologies for current and potential infestations.

This work was requested by Horizons Regional Council and funded from an Envirolink grant through the Foundation for Science, Research and Technology, Contract 444-HZLC48.

Figure 1: Hornwort (*Ceratophyllum demersum*) top, leaves in whorls of 7–12 forked with toothed margins and lagarosiphon (*Lagarosiphon major*) bottom, leaves arranged spirally and recurved.

2. Site description

The Tongariro Power Scheme is located on the Central Volcanic Plateau south of Lake Taupo. Water is diverted from the west and east into Lake Rotoaira to tap a catchment area of more than 2600 sq km. The Western Diversion begins at the Whakapapa River and intercepts water from four other streams and the Whanganui River into Lake Te Whaiau. From Lake Te Whaiau water flows into Lake Otamangakau and then into Lake Rotoaira via the Wairehu Canal (Fig. 2) which has a rotating screen to prevent transfer of larger biota such as lamprey. From Lake Rotoaira water is passed through the Tokaanu power station (240MW total capacity) into Lake Taupo and ultimately through eight further Waikato River hydro-electric dams below Lake Taupo.

Water is sometimes returned to the Whanganui River catchment, either to maintain minimum base flows in the Whanganui River (through a valve from Lake Otamangakau into a small creek feeding the head waters of the Whanganui River Fig.3), or spilt from Lake Te Whaiau over the weir (cover photo).

Lakes Te Whaiau, Otamangakau, and Rotoaira, are popular with recreational users, and boats move between the lakes. Access to Lake Rotoaira is limited to three sites; a public boat ramp access via the Poutu Canal (east end of the lake), through private land through a motor camp on the southern side of the lake, and from a side road near the Tokaanu power station intake (Fig. 4). Readily usable public boat ramps are available at Lakes Te Whaiau and Otamangakau (Figs. 7 & 8).

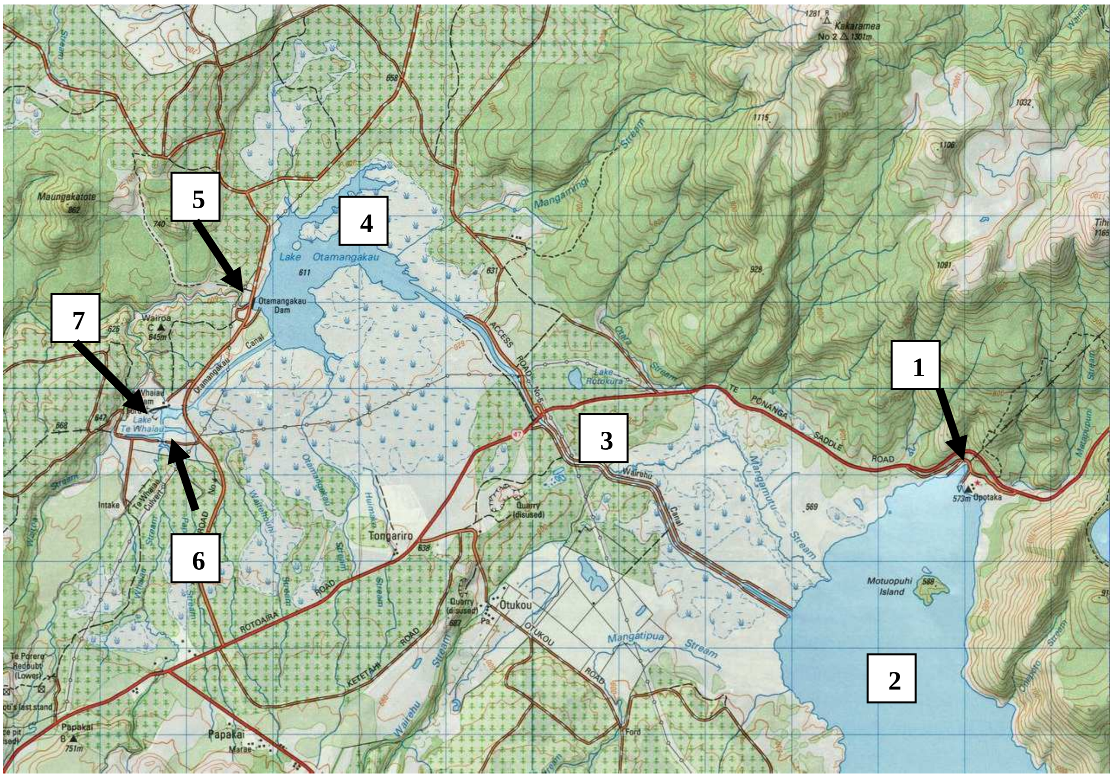

Figure 2: Part of the upper Whanganui and Waikato catchments showing: 1. Tokaanu Power Station intake; 2. Lake Rotoaira; 3. Wairehu Canal joining Lake Otamangakau to Lake Rotoaira; 4. Lake Otamangakau; 5. Otamangakau Dam; 6. Lake Te Whaiau; 7. Lake Te Whaiau weir that occasionally spills to the Wanganui Catchment. The Whanganui River passes immediately to the west of Lake Te Whaiau.

Figure 3: Lake Otamangakau discharges to the Whanganui River Catchment only occasionally.

3. Methods

The area in the vicinity of the upper Whanganui River (Fig. 2) was delimited for invasive aquatic plants on the 15th and 16th January 2008. We included Lake Rotoaira (SCUBA), Lake Otamanagakau (SCUBA) and Lake Te Whaiau (snorkel). The Whanganui River was accessed via the stream channel from the Te Whaiau weir and locations checked at road access points in the area visually from the surface. Also included were some earlier observations from previous surveys where relevant.

4. Weed distribution

4.1 Lake Rotoaira

The aquatic vegetation of Lake Rotoaira was first surveyed in 1966, again in the late 1960s, 1970s, 1999, and more recently in 2007 (Rowe et al. 2007). Hornwort was first observed in 1998 in Lake Rotoaira. It invaded quickly and in 1999 hornwort was recorded in 24 of the 25 sites surveyed, grew to a water depth of 10.4 m, had high area coverage and was the tallest weed in the lake with heights of up to 7 m. Hornwort and lagarosiphon (also in Lake Rotoaira) have had a major impact on the aquatic vegetation in the lake. Cover of elodea (*Elodea canadensis*), an introduced 'oxygen weed', was substantially reduced as a consequence of widespread displacement by hornwort and lagarosiphon and significant areas of native vegetation have been markedly reduced. Egeria (*Egeria densa*) was not found in the lake (or the study area), but is present in marinas in Lake Taupo.

Hornwort was present in the vicinity of both boat ramps in the lake in 2008 but not in the vicinity of the Poutu Canal boat ramp (Fig. 4). Hornwort has been recorded up to 7 m tall (Dugdale and Wells 2001) with large areas of surface reaching weed (Fig. 5) proving problematic for operating the Tokaanu power station (Fig. 6). This necessitated installation of a multi-million dollar system in 2007 (Fig. 6) to intercept the large quantities of weed arriving at the intakes.

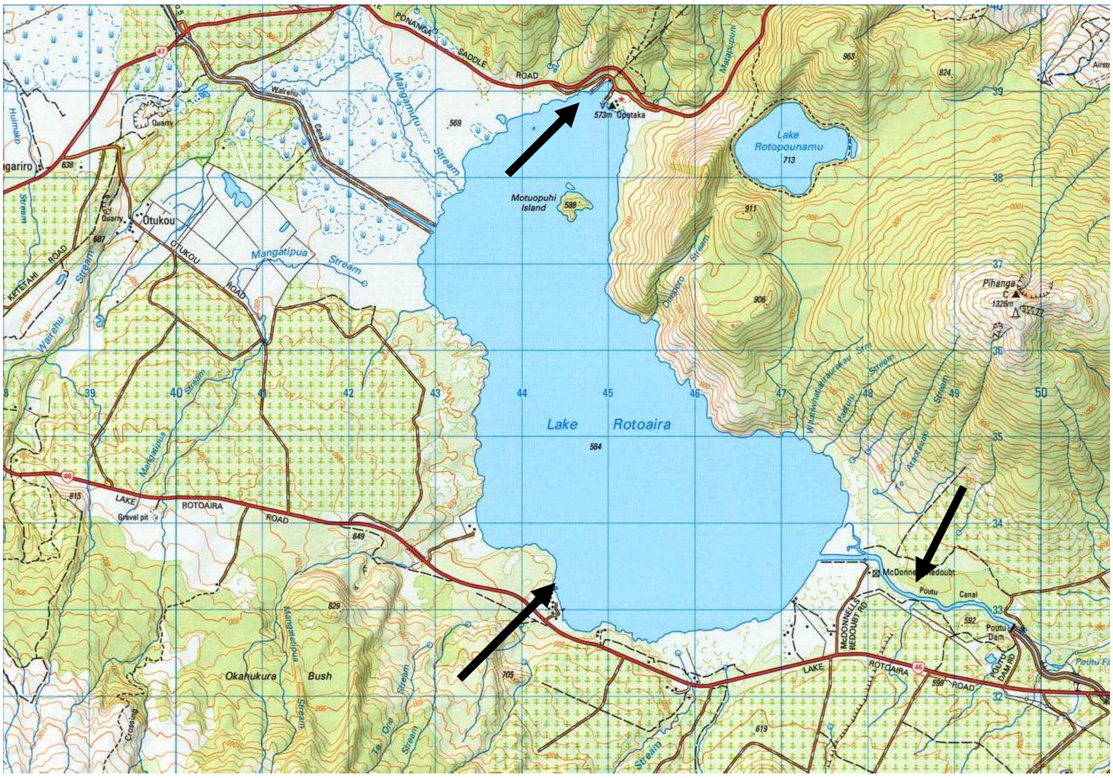

Figure 4: Lake Rotoaira boat ramps located as shown by arrows.

Figure 5: Lake Rotoaira with surface reaching hornwort in the foreground and Tokaanu power station intakes in background.

Figure 6: Tokaanu power station screens (left) intercept large quantities of hornwort removed via conveyor (right).

4.2 Lake Otamangakau

Lake Otamangakau (Fig. 7) was mostly vegetated and dominated by lagarosiphon (to 4 m deep) with some elodea but no hornwort. Native characean (nitella and chara species) vegetation occupied the deeper parts of the lake. Lake Otamangakau is a shallow lake (12 m maximum depth) and was formed by damming the Otamangakau and Te Whaiau streams.

Figure 7: Lake Otamangakau, showing boat ramp access.

4.3 Lake Te Whaiau

Lake Te Whaiau (Fig. 8) was formed by damming the Te Whaiau stream and received water from the Western Diversion. It was vegetated right across with lagarosiphon and elodea but no hornwort. The lake is shallow with the deeper parts little more than 3 m deep being where the old stream channel was. The lake is connected to Lake Otamangakau via a canal.

Figure 8: Lake Te Whaiau with lagarosiphon in the foreground and easy boat access (where the vehicle is) in the background.

4.4 Whanganui River

The Whanganui River and its upper tributaries (near these lakes) were not suitable habitats for aquatic weeds (Fig. 9). However, at Piriaka (near Taumarunui about 30km downstream) there is an impounded area at the intakes of the Piriaka power station where elodea grew (Fig. 10) sheltered from the high velocities that regularly occur in the main river channel. This was the only site where submerged weeds were found, despite many years of irregular discharges from Lakes Te Whaiau and Otamangakau that would have transported lagarosiphon and elodea to the Whanganui River catchment. I also canoed the river from Whakahoro down as far as Pipiriki 145 km downstream of Taumarunui and followed the river road to Wanganui. Likely areas were searched on SCUBA and with a grapnel but no submerged plants were found. The river from within about 10 km of Wanganui had suitable base flows for weed growth (<0.5 m sec^{-1}) but the water clarity (even after a long dry spell in late February 2008) was still quite turbid (0.5 m secchi) and with such a limited photic zone and significant water level fluctuations in the river the habitat was almost certainly limited by light availability.

The Ongarue River joins the Whanganui River at Cherry Grove, Taumarunui, and had areas of elodea where substrate and velocities permitted such as at the confluence with the Whanganui River and upriver near Ongarue township (Fig. 11). This would also be another source of weed inoculum to the Whanganui River.

Figure 9: The upper Whanganui River (top) at Highway 47 and (bottom) below Lake Te Whaiau had no submerged aquatic plants.

Figure 10: The upper Whanganui River at the Piriaka impoundment, near Taumarunui, had some elodea growing on the left bank only where protected from high flows by excess water being discharged over three weirs.

Figure 11: The Ongarue River, a tributary of the Whanganui River, showing a bed of elodea near Ongarue township.

5. Potential impacts

5.1 Hornwort

Hornwort (Fig. 1) is rated as New Zealand's worst aquatic weed (Champion et al. 2002) and is already widespread in Lake Rotoaira, where it has proven to be a major problem both for recreation and hydro power generation. Hornwort poses a considerable risk to Lakes Otamangakau and Te Whaiau because it could potentially become surface-reaching over much of these shallow lakes (12 m & 3 m deep respectively). The deepest parts of both lakes are within its c. 15 m maximum recorded depth range and hornwort was recorded growing to 10 m tall in Lake Whakamaru on the Waikato River, and to 7 m tall in Lake Rotoaira, where it grew to 10.5 m deep. Hornwort has a seasonal peak abundance in late summer with fragmentation and drift marked through late summer and winter in Lake Rotoaira, so could potentially clog the Wairehu canal rotating screen and accumulate \ rot against lee shores of the lakes in autumn and winter. Information about hornwort and potential impacts in New Zealand were covered in detail by Hofstra (2002). It has a potentially high nuisance value for the trout fishing in Lakes Otamangakau and Te Whaiau if large areas of surface reaching weed form making access to the lake difficult for boats and with drifting weed fouls hooks and would degrade the currently high aesthetic values in the area. It will also reduce native biodiversity displacing the native plant communities not currently impacted by lagarosiphon, which is restricted in it depth range.

Weed transfer to the Whanganui River is not considered to have a significant potential impact, as the river has very little suitable habitat for submerged aquatic plants. Also hornwort does not pose much risk in strong flowing water as evidenced in the Waikato River where it dominates in the hydro impoundments but not in the riverine sections. It is unlikely but possible the lower c. 10 km of the Whanganui River could be susceptible to hornwort and / or egeria invasion. Hornwort and egeria (*Egeria densa*) are the two dominant species in lower reaches of many New Zealand Rivers, however the lower Whanganui River is very turbid and water levels fluctuate well beyond the range of the photic zone.

5.2 Lagarosiphon

Lagarosiphon (Fig. 1) is present throughout Lakes Rotoaira, Otamangakau and Te Whaiau and has been present long enough to be habitat saturated and reached its maximum potential impact. However, it would have very limited potential habitat, if any, in the Whanganui River due to high flows. It has been dispersed into the river for years with irregular discharges from Lakes Te Whaiau and Otamangakau and there is no evidence of it having established to date. It can grow in flowing water but in cool water at higher flows, elodea is usually more competitive. Its potential impact in the upper Whanganui River is therefore likely to be less than that of elodea (see Section

5.3). It is mostly a clear water plant and less competitive than hornwort or egeria in nutrient rich, turbid water.

5.3 Elodea

Elodea (Fig. 12) was once very abundant throughout Lakes Rotoaira, Otamangakau and Te Whaiau. It has been almost totally displaced by hornwort and lagarosiphon in Lake Rotoaira and to a great extent by lagarosiphon in Lake Otamangakau, and Te Whaiau. Elodea is a very rapid primary coloniser in flowing water (< 1 m sec^{-1}) and is present in the Whanganui River at Piriaka. It would likely dominate at Piriaka even if lagarosiphon or hornwort were to naturalise there, because of the influence of flowing water. Elodea has been at Piriaka for at least four years and probably much longer nearby in the Ongarue River so has likely reached it potential impact in the river already. It would not be competitive in the turbid waters of the lower Whanganui River. Overall for both the lakes and the Whanganui River elodea is unlikely to have any further potential impact than that already seen.

Figure 12: Elodea (*Elodea canadensis*) is characterised by leaves in whorls of three.

6. Vectors for transfer of hornwort to Lakes Otamangakau \ Te Whaiau

The key consideration is how to prevent hornwort transfer to Lakes Otamangakau and Te Whaiau. The two are essentially one water body for this consideration as they are connected.

In New Zealand hornwort flowers but there is no evidence that viable seed is formed (Coffey and Clayton 1988), possibly due to a lack of favourable conditions (Mason 1975). Vegetative reproduction and dispersal of brittle stem material is the primary method of propagation and spread both within and between water bodies (Coffey and Clayton 1988). Fragmentation of stems is a highly successful means of propagation (Les 1991), and in areas with cold winters, the plants produce thickened lateral tips that are darker green in colour and contain an increased amount of starch (Best 1979, Best 1982). Water movement (drift) within a water body is the primary means of dispersal but inter-lake transfer requires human activity to carry vegetative fragments between water bodies. Birds have not been implicated with inter-lake transfer even though large numbers frequently move from lake to lake. Eel fishermen have often spread aquatic weed by not cleaning fragments from fyke nets when moving between waterways. It is understood that there is no eel fishing in these lakes. If there is, then this is a significant pathway for transfer of aquatic weed that would need to be considered.

Genesis already have protocols in place to prevent their activities and subcontractors causing weed to be transferred (they issue a copy of “Local Standing Instruction for Managing the Risk of Aquatic Weed or Algae Invasion into Waterways” to all subcontractors).

Hornwort could easily be transferred to Lakes Otamangakau and Te Whaiau as it would only take one inadvertent transfer of a small stem fragment. The most likely means of transfer would be either on an anchor / rope, in the bilge of a boat, on a boat trailer, or boat motor brought from Lake Rotoaira. With boats moving from Lakes Rotoaira (or other infested water bodies such as Taupo, or Waikato or Rotorua lakes) to Otamangakau \ Te Whaiau it is inevitable hornwort will be introduced in the near future unless effective controls are in place.

7. Options for preventing transfer of hornwort to Lakes Otamangakau \ Te Whaiau

Options to prevent introduction of hornwort include:

1. *Prevent all boat access to Lakes Otamangakau / Te Whaiau:* This would give the highest protection to lakes but the lakes are of high recreational fishing value and this option would largely prevent trout fishing in these lakes.

2. *Prevent motorised boat access*: This option has merit and has kept a number of lakes weed free for a relatively long time. Lake Otamangakau is relatively large and a small motor allows access to more distant parts of the lake. Even without motors there is still the issue of trailers, bilge water, anchors and anchor ropes potentially transferring fragments.

3. *Close boat ramps to prevent trailer access*; *ban any form of anchoring; and ban discharge of bilge water.* If these actions were supported by educational signage and accepted by all users then the risk of hornwort introduction would be minimised with the least impact on users. Preventing trailer access would limit boats and motors to those that could be carried to the waters edge only. It would make boat fishing Lake Otamangakau less attractive but will greatly increase the chances of preserving the quality of fishing indefinitely.

4. *Entry after close inspection by an inspector only*: This option is enforced in privately owned and some busy lakes overseas. It would cost the boat owners each time they launched and not be a practical option for this relatively remote part of New Zealand. It would be unlikely to gain community support though it could be an option for shorter periods of the year supplementing Option 3 when high use is expected.

5. *Early detection surveillance monitoring and a contingency plan for eradication*: A programme of regular surveillance may detect a hornwort invasion at an early stage. However, this has merit only if an effective eradication response plan is prepared and able to be implemented immediately. An effective response aimed at eradication would require rapid delimitation of the infestation followed by treatment of the whole infested area with either diquat (treating the total water column to 2 mgL^{-1}) or endothall (treating the total water column to 5 mgL^{-1}). Endothall treatment can be much more expensive. All necessary approvals would need to be obtained and in place prior to detecting hornwort to enable an early response to have any chance of successful eradication. It would be a costly exercise and have a low chance of success. Preventing an introduction would be far easier to

achieve than eradicating the plant once introduced, this option is more of a back-up option to other measures taken to prevent transfer.

6. *Use of a containment boom* (with netting to lake floor) and with a gate for boat passage through the boom from the boat ramp(s). Other areas that might otherwise be used for boat access would need to be close off. This option will still allow motorised boat access and provide a high chance of containment upon introduction with much more likelihood of early detection when combined with proposed surveillance. Bilge and anchor restrictions would still be needed.

7. *Educate the public on the risks, and on how to avoid introducing hornwort*: this is a useful option particularly for frequent users of the lake, but not one that can be relied on solely. Even with all the educational coverage devoted to didymo in the South Island, didymo continues to spread there. It only takes one person to be less than diligent to introduce hornwort.

8. *Status quo, use signage and allow free movement*. Hornwort must at some time soon be transferred under the status quo. The current signage (Fig. 13). is aimed at encouraging removal of weed as you leave, rather than specifically checking for hornwort before entering. This is in line with current legislation for containment of pest plants. The lake user may have left a lake in another region without such good signage. There is no sign at Lake Te Whaiau. The status quo will lead to hornwort introduction and a situation where annual weed control using an aquatic herbicide is necessary to maintain the current popularity of the fishery.

The question that managers and the community need to address is what level of compromise is warranted from lake users for what level of protection from hornwort invasion.

Figure 13: Signage at the Lake Otamangakau boat ramp. Good signage but note elodea is pictured above the egeria caption; elodea is a plant not covered by the National Pest Plant Accord (NPPA) and is available for sale and distribution.

The recommended option, to minimise the risk of transfer, is to prevent trailer access to the lakes (or restricting it to netted areas with boat gate); ban anchoring and bilge water discharge within the lakes backed up with signage warning of the consequences of hornwort introduction and how it can be avoided.

8. Surveillance \ monitoring

A regular surveillance programme such as a snorkel and SCUBA inspection of boat ramp areas once or twice a year could detect a hornwort invasion at an early stage. However, this has merit only if an effective response plan is able to be implemented immediately and only if there is a realistic chance of success. An effective response would require rapid delimitation of the infestation, followed by treatment of the whole infested area with either diquat (treating the total water column to 2 mgL^{-1}) or endothall (treating the total water column to 5 mgL^{-1}). All necessary approvals (consents, possibly ERMA permission, and wider community consultation) would need to be obtained and in place prior to detecting hornwort to enable an early response to have *any* chance of success. Preventing the introduction of hornwort is far easier than attempting to control it once introduced as eradication would probably be an impractical option.

If hornwort became widespread in Lakes Otamanagakau and Te Whaiau the only practical way to control it would be to use the aquatic herbicide diquat. A December application annually targeting areas of nuisance would prevent surface reaching growths. Details of diquat and endothall (the two herbicides registered in NZ) follow.

9. Control options

Control options that have been investigated in New Zealand and overseas for hornwort are many and broadly cover the categories of habitat manipulation, mechanical harvesting, biological control and chemical control. Some of these methods have subsequently been considered to be of little benefit and other methods are only appropriate for particular water bodies. Few have the potential to eradicate hornwort. Grasscarp and chemicals are both controversial options but largely through public mis-information. Chemicals are the only practical option for weed control in these lakes, so a wider consideration of the alternative options and more detail on the chemical option is provided to enable a better informed choice to be made.

9.1 Habitat manipulation

Habitat manipulation is a broad term covering a wide range of scenarios where some aspect of the habitat is manipulated (i.e., water, and light,) to reduce plant growth. There are many alternatives in theory but not in practice. Lake drawdowns have been implemented both in the USA and New Zealand for the control of hornwort. Consecutive lake drawdowns have been advocated to achieve good control of hornwort in the USA (Wade 1990). In New Zealand in the 1960s and 1970s lake drawdown was frequently used as a means of controlling hornwort and the growth of other nuisance submerged species in hydroelectric dams (Johnstone 1987). Lake lowerings in summer or winter were used to desiccate weed masses and to freeze-kill weed masses, respectively in the 1 to 4m depth zone (Howard-Williams 1993). In some instances weed beds did not die and remnant patches simply became the foci for renewed growth (Coffey 1975). Hornwort is capable of immediate regeneration after lake lowering events, regaining its former biomass in five months (Hughes 1976). Since 1976 lake lowering for weed control has not been carried out for several reasons including the cost of lost power generation, the short-term effect of lowering a lake which needed to be repeated at least annually to be effective, and the unfavourable impacts on biota (Johnstone 1981). Ultimately the most cost effective method of controlling weeds by generating authorities has been at the station rather than at the source in the lake. This has been achieved through weed booms to protect the inflow to the penstocks and screen cleaners protecting the turbines (Johnstone 1981). Other methods such as shading with trees or bottom lining are not relevant for the lakes in question.

9.2 Mechanical

Mechanical diggers, weed harvester, suction dredging and even hand weeding on a small scale can be used to reduce weed biomass in lakes, drains and other waterways (www.niwa.co.nz/rc/prog/aquaticplants/weedman). Cutting, harvesting, and mulching of weed occurs in the Waikato River hydro lakes but is around 10 times more expensive than the use of chemicals and only removes weed in the top metre or so of water. Disposal of the harvested weed is also about as expensive as cutting it. These methods are not suitable for large areas of weed beds to be controlled unless considerable funding is available long term.

9.3 Biological

Potential biological control agents investigated for use on hornwort include snails, nematodes and fish.

The nematode (*Hirschmanniella caudacrena*) has been found in high populations in the tissues of hornwort in the USA (Gerber and Smart 1987). Hornwort is considered a substantial problem in Connecticut, Indiana, Iowa, Minnesota, Ohio, Virginia, Wisconsin and Alabama. In controlled experiments *H.caudacrena* was pathogenic to hornwort, causing chlorotic tissue, deformed stems and finally plant death. However it was concluded that due to the high innoculum levels needed it was not practical to use *H.caudacrena* alone as a biocontrol agent (Gerber and Smart 1987).

In Florida and Puerto Rico the freshwater snail *Marisa cornuarieties* L reportedly eradicated a large variety of submerged aquatic plants including hornwort (Gerber 1985). This snail (*Marisa cornuarietis*) was introduced into New Zealand for evaluation as a potential biocontrol agent. However subsequent studies showed that the snail was also carnivorous, and was a health risk as it could convey cercariae larvae of the liver fluke parasite, and weed control would require very high population densities (Chapman et al. 1974). At that time grass carp (*Ctenopharyngodon idella*) were showing greater potential to control aquatic plants, including hornwort. Studies in New Zealand and overseas have shown that grass carp eat hornwort (Wells et al. 2003) and can potentially eradicate it and other nuisance submerged weeds. They are however not suited to feeding at low temperatures that are prevalent in trout fisheries such as in the lakes in question, otherwise it would be a suitable option.

9.4 Chemical

The ideal herbicide would:

- Kill target species and be cost effective.
- Be only toxic to the target species and non-toxic to other life.
- Be of no risk to Human health.
- Not be bio-concentrated, but be metabolised / excreted if ingested.
- Biodegrade to innocuous elements.
- Be short lived.

In overseas studies, a wide range of chemical products have been evaluated and advocated for the control of hornwort including, 2,4-D, paraquat, acrolein, fluridone, simazine, dichlobenil, diquat, endothall and copper (Westerdahl and Getsinger 1988, Helsel et al. 1996, Kay et al. 1983, Murphy and Barrett 1990, Best and Wittenboer 1978, Clayton 1986).

In New Zealand diquat and endothall are the two chemicals registered for the control of submerged plants. Diquat is a short-lived contact herbicide that can be used safely in lakes, drains and other waterways on a number of plant species, including hornwort. Diquat is used to control hornwort in Rotorua lakes, as well as Lakes Karapiro, Whakamaru and Atiamuri. Costs for diquat treatments start from about $1,200 per ha.

Endothall has recently been registered for aquatic use in New Zealand and was evaluated in a field trial in drainage channels choked with hornwort in the Wairarapa. Hornwort was effectively controlled with endothall (Hofstra and Champion 2001). Costs for endothall treatments start from about $3,000 to $15,000 per ha depending on concentrations and formulation of endothall used.

9.4.1 About diquat

In New Zealand, diquat is a registered herbicide for use in natural water bodies. The active ingredient is available as two formulations: an aqueous solution, and a gel that sinks.

NATURE AND MODE OF ACTION OF DIQUAT

Diquat is a quick acting contact herbicide, which has minimal translocation within plants. Its mode of action is by interruption of the electron transport system in plant photosynthesis, resulting in the formation of hydrogen peroxide, which then desiccates green plant tissue. Submerged aquatic plants rapidly absorb diquat and it is also strongly adsorbed and inactivated by both inorganic and organic compounds within the water and bottom sediments of aquatic ecosystems. In this way the performance of diquat is reduced in turbid water or where plants are covered in deposits of silt, which rapidly bind up the diquat. Diquat is a selective herbicide and this is usually a strong point in its favour. It has been demonstrated to control most target nuisance weed species (elodea, egeria, lagarosiphon and hornwort) while leaving many of the native plant species unaffected.

TOXICITY

All agricultural chemicals are classified as to their degree of hazard. Those classified as poisons range from Class 1 (deadly poisons), to Class 2 (dangerous poisons) and to Class 3 (poisons). Diquat in its concentrated form is a Class 3 poison and is therefore a hazardous substance. When diluted 100,000 times (or more) to allowable concentrations in water for control of water weeds (2 ppm or less, diquat dibromide salt), it is relatively safe to the extent that in the U.S.A. the swimming restriction has been lifted for diquat treated water (i.e., swimmers are not prevented from water contact immediately after diquat application for the control of weeds). Following the application of diquat to water, the concentration of active ingredient rapidly declines as a result of dispersion, plant uptake and adsorption to organic and inorganic (negatively charged) particles. This is also consistent with other field studies in New Zealand and most of the overseas work (except where the whole of a static water body is treated). A range of studies has shown that diquat is non-mutagenic up to levels that would otherwise cause cellular damage. It is also non-carcinogenic. Adsorbed diquat has no residual toxicity, is not biologically active and is degraded slowly by microbial organisms within sediments. A comparison of diquat with other well known substances in everyday use shows caffeine and particularly nicotine to be considerably more toxic:

diquat cation LD50 (lethal dose) = 600 - 800 mg kg^{-1}

caffeine LD50 = 192 mg kg^{-1}

nicotine LD50 = 50 mg kg^{-1}

In other words, a much higher amount of diquat is required to achieve a toxic effect on test organisms compared to caffeine or nicotine. Chronic (long-term) toxicity studies on dogs and mice show the no observable effect limit to be between 0.5 and 4.5 mg/kg /day. This would be the equivalent intake of a 70 kg person consuming between 35 and 315 litres of diquat treated water (shortly after application). To be protective of adverse human health affects the USEPA set a one day advisory concentration of 0.2 ppm (diquat cation) for drinking water, based on a 10 kg child receiving it for up to 5 consecutive days. The tolerance level for shellfish as food is 20 ppm. Diquat concentrations of 30 ppm are considered safe for human skin contact. Based on the information above it is evident that the 24-hour post-treatment prohibition period for swimming and drinking in New Zealand is a very conservative safety precaution, which is designed to prevent any possible mishap, but at the same time it has the disadvantage of unduly heightening the public perception of hazard. In the U.S.A. there is no withholding period for swimming and the drinking water life time exposure concentration is 0.08 mg l^{-1} (diquat cation), which would normally occur within an hour or so of application.

EFFECTS ON ECOLOGY

Diquat is in most cases at least ten fold more toxic to aquatic plants than to aquatic animals. It does not kill fish at rates required to kill aquatic weeds. Tests on diquat show the active ingredient (the diquat cation) must be higher than 10 mg 1^{-1} for lengthy periods for mortality in most fish. Trout are one of the most sensitive fish species known, with an LC50 (96 hrs) of 6.1 – 18.7 mg 1^{-1} (that is the lethal concentration at which 50% of test organisms died after a 96-hour exposure). For early life stage toxicity, the chronic (21- day) LC50 was determined to be 2.9 ppm (diquat cation). Other fish species such as eels are considerably more tolerant. The most sensitive aquatic organisms to the diquat cation are amphipods (minute crustaceans), which have an LC50 (96 hrs) of 0.05 mg 1^{-1}. Overseas studies have shown that even juvenile freshwater crayfish (which are considerably more vulnerable than adults and also more sensitive to paraquat than to diquat), had an LC50 for paraquat of over 5 mg 1^{-1} diquat cation. In view of the rapid dispersion, adsorption and resulting exponential loss of diquat that occurs following application, undesirable toxic impacts would not be expected.

There is no evidence of food chain accumulation from repeated use of diquat. Field studies on lakes that have been treated with diquat regularly for over 40 years in New Zealand have not recorded any detrimental changes in the resident fisheries or benthic organisms that are attributable to diquat toxicity.

EFFECTS OF DE-OXYGENATION ON AQUATIC ECOLOGY

By far the greatest hazard to aquatic life comes from de-oxygenation rather than from diquat toxicity. All aquatic organisms require oxygen for life. Decomposition of weeds treated with diquat uses oxygen from the water during the decay process. The most important factors affecting dissolved oxygen depletion are the amount of biomass of decaying weed and re-aeration rate. These are affected by the amount of open water, the degree of water movement and temperature. In warm temperatures, the saturation capacity of water is less and decay rates are more rapid causing greater de-oxygenation than when water temperatures are cool. To minimise deleterious impacts associated with de-oxygenation it is preferable to treat weeds during spring or autumn months if large quantities of weed are expected to decay in small volumes of water. Summer treatment is acceptable where applications are small relative to water volume. De-oxygenation need not be a threat to aquatic organisms if standard precautions are taken with respect to timing of treatment, application rates used and area to be treated at any one time. No weed control in a water way can often lead to excessive weed cover that can also detrimentally impact on oxygen levels overnight (plants respire) and kill aquatic fauna. In the absence of any control many nuisance introduced species are capable of covering the water surface and severely impeding flow in many situations, thereby presenting management and user problems as well as impacting on aesthetic values. As opposed to the previous statement, total removal of aquatic plant growth may also undesirable ecologically, as it impairs the habitat for aquatic fauna. Targeting of nuisance levels of weed species can be an acceptable and even desirable practice that can have both use and ecosystem benefits.

EFFECTS OF DIQUAT TREATED WATER ON IRRIGATION

Ground irrigation of crops using water treated with diquat for weed control is not problematic, however over-head irrigation could have an effect. The standard withholding period in New Zealand for overhead irrigation is 10 days for static water and 24-hours for flowing water (label recommendation). This is exceptionally conservative. Diquat has been used as an aquatic herbicide for over 40 years without a single case of phytotoxicity being reported due to the effects of irrigation water. Most crops irrigated at up to 0.5 ppm (diquat cation) are not likely to be damaged. Irrigation studies with water containing 0.01 ppm have shown no evidence of phytotoxicity or residues higher than the U.S. FDA tolerance. At much higher exposure rates (>0.45

ppm) no evidence of damage or residues higher than the allowable tolerance of the USEPA was seen in potatoes, sorghum, soybeans, carrots, lettuce, or onions.

9.4.2 Endothall compared with diquat

Endothall vs	Diquat
Active ingredient dipotassium endothall; endothall acid 36%	Diquat dibromide; diquat cation 20%
Application rate is 3-5 ppm calculated as volume of weed bed	Up to 30L per ha = 1-2 ppm for 0.3m depth of water
Targets hydrilla, hornwort and lagarosiphon	Targets hornwort, lagarosiphon, elodea, egeria, and vallisneria
Little effect on tall natives, elodea, egeria vallisneria and charophytes	Little effect on tall natives, hydrilla and charophytes
Acceptable human daily intake 0.028 mg/kg/d (USEPA)	Acceptable human daily intake 0.005 mg/kg/d (USEPA)
ERMANZ tolerable environmental limit TEL 0.28 ppm	TEL not set for NZ; in the US* it is 0.04 ppm; 0.01 ppm allowable in drinking water
3 day fishing restriction, though has now been lifted in the US*	No fishing restriction in NZ
24h swimming in NZ; none in the US*	24h swimming in NZ; none in the US*
Withholding periods: domestic use or livestock and irrigation = 14 days below 4.25 ppm; 25 days up to 5 ppm; or until below 0.28 ppm.	Withholding periods: domestic use or livestock = 24h, for irrigation (static) 10 days or until below 0.01 ppm.

*US labels are updated frequently. NZ labels are rarely changed so are often outdated.

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