A Ten Year Lagarosiphon Management Plan for Lake Wanaka: 2016-2025

Prepared for Land Information New Zealand and Boffa Miskell

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The Lake Wanaka Lagarosiphon Management (LWLM) Committee support the intentions of this document in guiding the management of lagarosiphon at Lake Wanaka.

Agency	Representative	Signature
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Guardians of Lake Wanaka	Don Robertson (Chair)	
Otago Regional Council	Jeff Donaldson	
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Executive summary

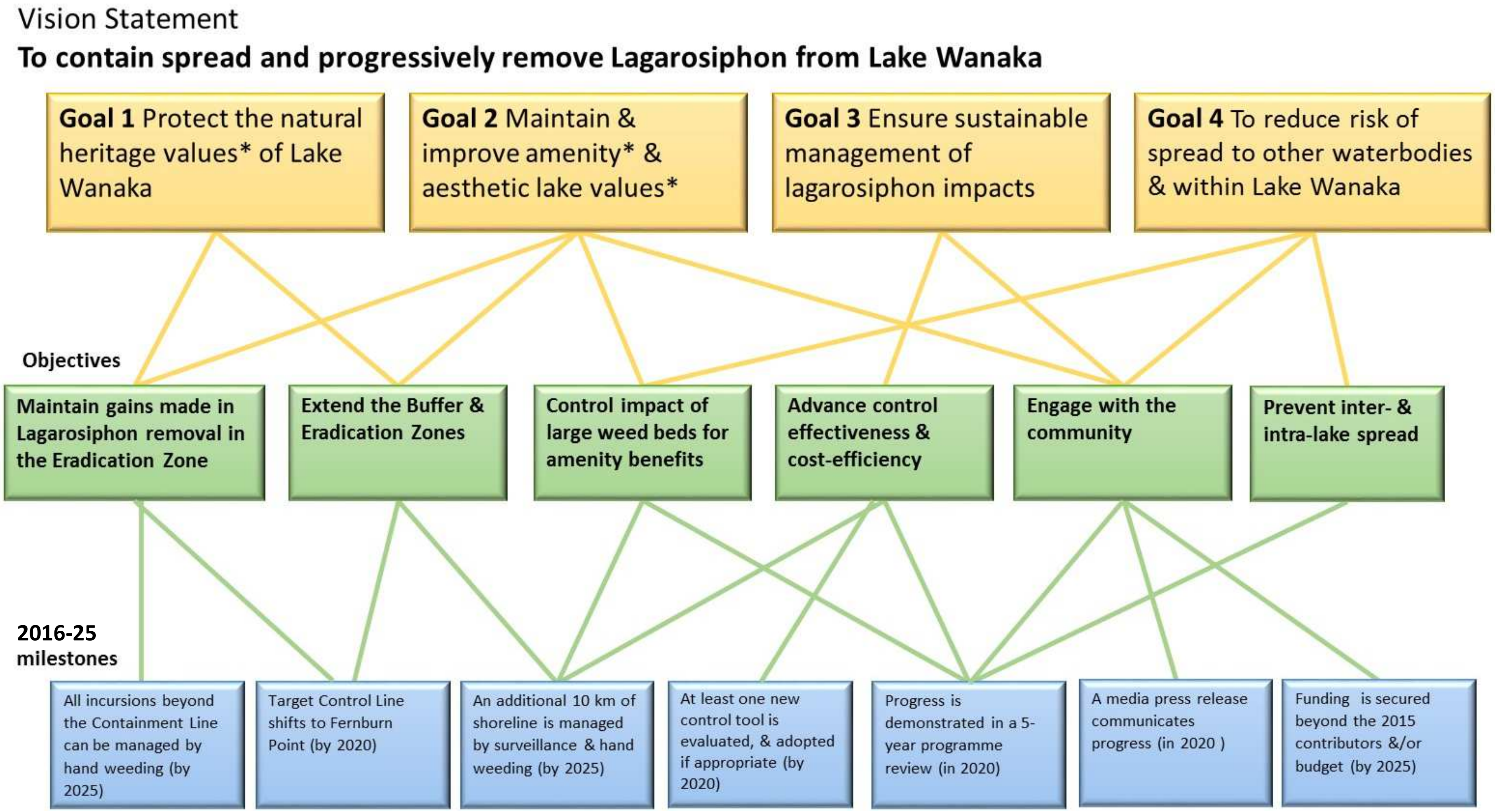
Lake Wanaka is considered a national treasure due to its outstanding natural values. Some of these values are under threat from the incipient risk posed by the presence of *Lagarosiphon major*, one of the worst invasive water weeds in New Zealand.

This strategic review of the previous (2005) Lagarosiphon Management Plan will provide a long-term (ten year), shared vision for lagarosiphon control works in Lake Wanaka. The plan will be implemented by the lead agency Land Information New Zealand (LINZ) and the Lake Wanaka Lagarosiphon Management (LWLM) Committee, which also comprises The Guardians of Lake Wanaka, Otago Regional Council, Queenstown Lakes District Council, and Department of Conservation. LINZ biosecurity service partner, Boffa Miskell, plan and oversee the annual works programme and this document will also help communicate required actions with science advisers (NIWA) and contractors undertaking control works.

This document presents a vision statement, and interrelated goals, objectives and milestones (Figure 1) to guide management over the next five to ten years. Information on the ecology and status of lagarosiphon and likely impacts on the values of Lake Wanaka and Otago Region is provided as background to the nature and need for management. A description of the current status of lagarosiphon provides a benchmark against which future progress can be judged. The document also outlines some risks to the programme that should be recognised and mitigated as far as possible.

For management over the short-term, a suggested control programme for the 2015/16 year is outlined, with a rationale given for the use of specific control methodologies and their tactical application at different sites. In the medium to long-term a number of operational milestones are identified to gauge progress and recognise achievements contributing to the identified goals and objectives of the programme. Important to the success of the programme will be continual re-assessment of achievements and progress, incorporating a five-year review process in 2020.

Figure 1: Interrelated goals, objectives and milestones of the Lagarosiphon Management Plan 2016 - 2025.



*See definitions Appendix A

1 Introduction

Lake Wanaka is considered a national treasure due to its outstanding natural values. Some of these values are under threat from the incipient risk posed by the presence of *Lagarosiphon major*, one of the worst invasive water weeds in New Zealand.

This document revisits the 2005 lagarosiphon management plan for Lake Wanaka[1] to update contemporary knowledge on lagarosiphon and control techniques, and to outline strategic and tactical responses to combat the spread and impacts of lagarosiphon in Lake Wanaka. This revision recognises the current lagarosiphon status and advances made in the last ten years. Specifically, the document seeks to provide a shared, long-term view of lagarosiphon control in Lake Wanaka. This plan will be implemented by a multi-agency group represented by the Lake Wanaka Lagarosiphon Managers' (LWLM) Committee and comprising Land Information New Zealand (LINZ), The Guardians of Lake Wanaka (The Guardians), Otago Regional Council (ORC), Queenstown Lakes District Council (QLDC), and Department of Conservation (DOC).

2 Ten year management plan 2016 – 2025

2.1 Vision statement

An overall vision statement which encapsulates the purpose and outcomes sought is:

To contain spread and progressively remove Lagarosiphon from Lake Wanaka

2.2 Management Goals

The 2005 plan emphasised protection of unique natural heritage values of the lake, moving beyond the containment and amenity control focus of prior years. Also stressed was an adaptive management approach with regular monitoring and review of progress. This current plan revision recognises and builds upon the intent of, and progress achieved, by the previous plan.

Four high level goals are identified for 2016 to 2025 (Figure 1):

Goal 1 Protect the natural heritage values of Lake Wanaka

Lake Wanaka has a reputation as an unspoilt lake of outstanding natural value. Features such as high biotic diversity, clear blue waters and clean shorelines are threatened by uncontrolled establishment of lagarosiphon.

Goal 2 Maintain and improve amenity and aesthetic lake values

Lagarosiphon growth at popular recreational areas reduces the utility and enjoyment of the lake by the community and visitors. Targeted control can minimise impacts in these areas. Risk to public safety will be paramount in control considerations.

Goal 3 Ensure sustainable management of lagarosiphon impacts

Management of lagarosiphon has to be efficient and cost-effective to be viable in the long-term. It also has to be acceptable to and supported by the community. The use of herbicides can be emotive and controversial. However, this control tool is essential to the programme at this time and any risks posed by the herbicide can be mitigated by appropriate precautions on its application. A move towards reduced extent of herbicide use is compatible with the aims of the control programme through advances sought in herbicide application and efficacy, and through ongoing control progress.

Goal 4 To reduce risk of spread to other waterbodies and within Lake Wanaka

Lagarosiphon in Lake Wanaka represents a threat to other, uninvaded waterbodies in the Otago and adjacent regions. Reducing this risk requires targeting of the pathways of spread by increased public awareness and reduced recreational contact with lagarosiphon beds. Actions to prevent intra-lake spread will also help to reduce inter-lake spread.

2.3 Management Objectives

To support the goals in Section 2.2, six objectives are identified for the next five to ten years (Figure 1):

1. *Maintain gains made in Lagarosiphon removal in the eradication zone.*

Considerable progress has been made within the Eradication Zone north of the LINZ Containment Line (Appendix A) and this extensive northern lake area is currently protected from adverse impacts of lagarosiphon. Inability to maintain this status would require higher intensity surveillance and control measures in the future, and would result in reduced progress elsewhere in the lake. Surveillance and maintenance hand weeding must continue beyond the Containment Line, with zero tolerance for outlier colonies.

2. *Prevent inter- and intra-lake spread.*

Proactive containment of lagarosiphon infested sites in Lake Wanaka is more cost-effective than reactive management of new incursions. To prevent intra- and inter-lake spread sourced from Lake Wanaka requires the ongoing removal of lagarosiphon biomass from boat ramps, the marina, jetties, popular beaches and anchorage bays where watercraft are likely to pick-up fragments. The LWLM Committee will work with ORC and adjacent regional councils to advocate containment and actions to reduce the threat of new incursions. The Check, Clean and Dry programme initiated by the Ministry of Primary Industries (MPI) should be supported at each of the key lake launching sites, especially during periods of high recreational use and boat traffic.

3. *Extend the Buffer and Eradication Zones.*

To strategically extend the progress made in the lake, a 'control front' will be initially focused on the Glendhu Bay to Fernburn foreshore, with a view to reducing the Targeted Control Zone and expanding the Buffer Zone to cover this area. Longer-term the goal is to achieve control with maintenance hand weeding only and incorporate the area into the Eradication Zone.

4. *Control impact of large weed beds for amenity benefits*.

Community and recreational users should not have their activities and enjoyment of Lake Wanaka severely curtailed by impacts from lagarosiphon. Furthermore, reduction of nuisance weed beds will also reduce watercraft contact with, and transfer of lagarosiphon.

5. *Engage with the community.*

An informed and engaged public are less likely to spread lagarosiphon if they understand the risks posed to native biodiversity, recreational utility, property values and the unspoilt reputation of Lake Wanaka. The intent of the control programme, and progress achieved need to be communicated, and any concerns addressed. One recommended action is to develop and maintain a communications strategy for the lagarosiphon control programme. Additional public initiatives should be sought wherever possible (e.g., boater self-check forms, education campaigns).

6. *Advance control effectiveness and cost-efficiency.*

Increasing the effective outcomes from lagarosiphon control and improving cost-effectiveness has been an important objective of this programme to date and will continue to be applied to ensure greater efficiencies and faster progress is achieved. There will be a need to adapt tactics and techniques as progress is made, new knowledge becomes available, or efficiencies are identified. Some methods (i.e., bottom lining, endothall) need to be trialled under Lake Wanaka conditions before widespread adoption can be considered. Other initiatives (e.g., mulching, deep-water disposal, alternative gel formulations) may allow significant budgetary savings.

3 Agencies: interests and responsibilities

The Lake Wanaka Lagarosiphon Management (LWLM) Committee has multi-agency representation from five signatories to a previous 2004 Memorandum of Understanding. These include:

Land Information New Zealand

Land Information New Zealand (LINZ) is the lead government agency and is responsible for the management of the bed of Lake Wanaka and associated weed and pest control programmes. LINZ represents the Crown as owner of the lakebed pursuant to the Land Act 1948.

Guardians of Lake Wanaka

The Lake Preservation Act 1973 defines The Guardians' responsibilities. These include the maintenance and improvement of water quality, protection of the shoreline and matters associated with the use of the lake for recreation.

Otago Regional Council

Otago Regional Council (ORC) administers the Regional Pest Management Strategy (RPMS) under the Biosecurity Act 1993 that includes provisions for lagarosiphon control and monitoring.

Queenstown Lakes District Council

Queenstown Lakes District Council (QLDC) administers the District Plan that regulates land use activities including activities on the shoreline, bed and surface of Lake Wanaka. Together with ORC, QLDC is responsible for RMA bylaws and consents in relation to activities and structures on the lake.

Department of Conservation

The Department of Conservation's (DOC) primary role is to implement the Conservation Act 1987. One of its roles under this Act is to advocate for the protection of freshwater species and their habitats, on and off public conservation land. DOC also administers the Freshwater Fisheries Regulations 1983 under the Conservation Act 1987, making it one of the authorities for applications to move and possess freshwater species, including some pest species. DOC has an opportunity, in some situations, to provide support and specialist advice within the Resource Management Act 1991 processes, including resource consent applications, plan development, and the development of national guidance. DOC supports MPI and other agencies by advocating under the Biosecurity Act 1993, and supporting containment and management of threats and pests.

DOC also carries out the service delivery of aquatic weed control at sites of high importance under Acts it administers (e.g., National Parks Act 1980, Conservation Act 1987). DOC may also carry out aquatic weed control on private land, with permission from the landowner, to treat newly emerging aquatic weeds that have the potential to spread to high value sites.

Another agency with responsibilities for weed control in Lake Wanaka is:

The Wanaka Marina Company

The Marina Company are responsible for weed control works in an area extending 50 m from the furthest point of the Marina in all directions. However, the Roys Bay boat ramp and public jetty, are controlled under the LINZ lagarosiphon management programme. Wherever possible the Wanaka Marina Company synchronizes weed control works with the LINZ programme, and the outcome of weed control is inspected and reported back to the Lake Wanaka Marina Company under the auspices of the LINZ programme. This management plan review would support the incorporation of the marina area into the LINZ lagarosiphon control programme should agencies come to an agreement that was acceptable to both sides.

Future developments and additional agencies

The LWLM Committee will advocate for conditions to be placed on any future Consents granted for structures on the bed of the lake, to take due regard of implications for freshwater biosecurity, and for the development agencies to make appropriate financial contributions towards the LINZ lagarosiphon programme.

4 Background

Lagarosiphon ecology and status.

Lagarosiphon (*Lagarosiphon major* (Ridley) Moss ex Wager), also known as oxygen weed or African elodea, is a submerged, perennial macrophyte of freshwaters. Plants are characterised by strongly recurved leaves that are arranged spirally (see frontispiece) and close-packed along each stem, even more so towards the shoot apex[2]. Stems are long, slender, much branched and brittle. In older plants, a 'root crown' of woody stems is found at the base of the plant with roots extending into the sediment. Roots can also develop from nodes along the stem, which aid in the horizontal spread and colonisation by lagarosiphon. Even in its native range (Southern Africa) lagarosiphon reproduces primarily by vegetative means[3], and rarely fruits[4]. Lagarosiphon has been recognised as invasive in Ireland[5], the Netherlands[6] United Kingdom, France, Belgium, Switzerland, Italy, Réunion Island, as well as New Zealand[7].

Only female lagarosiphon plants are present in this country[2] . Despite being clonal and having very little genetic variation, lagarosiphon shows adaptation to a range of environments[8].

Lagarosiphon reproduction in New Zealand is entirely vegetative through stem fragmentation or horizontal spread from fallen stems. Buds are located at the apices of plants and at intervals at nodes along the stem. On average, lagarosiphon has one bud every 238 mm of stem length[9]. The minimal viable fragment size is not known, however is thought to be relatively small based on a reported 7.5 mm length (including a bud) for viable fragments of the related weed *Egeria densa*[10]. Viable apical fragments of 250 mm length were able to survive out of water for 20 hours at 20°C and 50% relative humidity, with death associated with a 70% loss in fresh weight[9]. Both this ability for small fragments to act as propagules, and short-term resistance to desiccation, means lagarosiphon may establish and form a new infestation at a new site from the transport and survival of just one viable fragment.

Human activities facilitate the spread of viable fragments via cultivation and release of plants or deliberate and accidental transfer between waterbodies. Although waterfowl have been suggested to spread weed there is no evidence they are a vector for lagarosiphon. Instead lagarosiphon distribution in lakes is significantly associated with boating and fishing activities[9]. In a statistical modelling approach the known distribution of lagarosiphon in New Zealand lakes was best explained by roading development and human population densities around infested lakes as measures of recreational access[11].

Lagarosiphon was first reported as a naturalised species in New Zealand in 1950. It was introduced by the aquarium and pond plant trade[12] and initially spread via domestic sales of plants. Subsequently, spread has been mainly by recreational boat traffic between lakes. The first record of lagarosiphon in Lake Wanaka was in 1972[13]. Currently, the closest sites of lagarosiphon to Lake Wanaka are the Clutha River, Lake Dunstan and Kawarau River, with records also in Canterbury, West Coast and Southland Regions (Figure 2). However, there remain numerous lakes in the vicinity that have not been invaded by lagarosiphon (Figure 2).

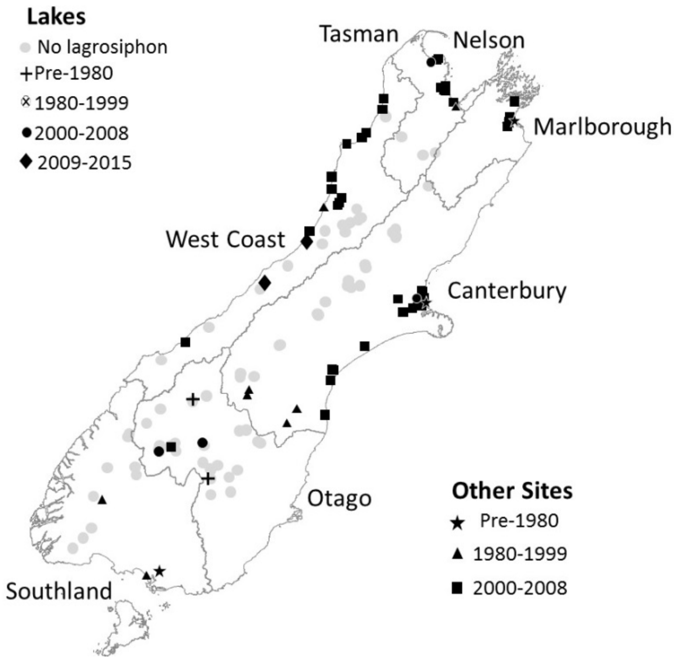


Figure 2: Distribution of lagarosiphon records in the South Island. Note some small sites have since been eradicated. Map modified from de Winton et al. (2009).

Once present in a lake, lagarosiphon can grow to a depth of 6.5 m, and up to 5 m in height. It can develop large beds at shorelines that are sheltered from prevailing winds and consequent wave action[14 15]. For instance, nuisance surface reaching weed beds were limited to areas with a wind-wave fetch <4 km in Lake Taupo[15], but subsurface bands of weeds and scattered colonies may develop over time on more exposed shorelines. Weed beds are also more restricted along steep shorelines.

New Zealand legislation provides for a pest status for lagarosiphon. Sale and distribution of plants has been prevented since 1982. A cooperative agreement (National Pest Plant Accord) between central government agencies, local government agencies and the Nursery and Garden Industry Association has maintained the prohibited status of lagarosiphon under the provision of the Biosecurity Act (1993) with the designation of 'Unwanted Organism'.

The Regional Pest Management Strategy for Otago Region[16] lists lagarosiphon as having a 'Containment' status in the southern region of Lake Wanaka that is designated a 'Lagarosiphon Containment Area'. This area may be redefined in future, in consultation with agencies involved in lagarosiphon management. Lagarosiphon is also managed for containment and amenity in specified 'Lagarosiphon High Value Areas' in Lake Dunstan and the Clutha River. Elsewhere in Otago Region lagarosiphon is designated a 'Total Control Species'. The Operational Plan for the Pest Management Strategy for Otago that covers the period 2009 to 2019[17] states a key activity as 'monitor the spread of Lagarosiphon'… 'where they are known to exist, and those water bodies with risk of establishment'. Lagarosiphon is also noted in Regional Pest Management Strategies for eight other regions including adjacent West Coast, Canterbury, and Southland Regions. Additional legislation (Section 53 of the Conservation Act 1987) prohibited the intentional introduction of new organisms into waterways unless permitted by the Minister of Conservation.

Known ecological impacts.

Impacts by lagarosiphon are associated with the plants architecture and typically high biomass, which differs fundamentally from the native plant assemblages found in New Zealand lakes. Lagarosiphon is considered to have a competitive advantage over native submerged plants in colonising new habitats easily[18], by shading native plants through the development of an extremely dense subsurface canopy and by having a physiological advantage over potential competitors[19]. Consequently, lagarosiphon displaces and excludes native vegetation leading to monospecific beds of low diversity[2 20].

Differences have been detected in the composition of aquatic insects, termed macroinvertebrates, between lagarosiphon beds and native vegetation, with increased dominance by chironomids and snails in lagarosiphon beds but no obvious difference in overall diversity [14 21]. In Lake Wanaka the abundance of macroinvertebrates was higher per unit area within taller lagarosiphon beds than the lower-stature native vegetation at an equivalent depth[21]. However, where lagarosiphon biomass in Lake Dunstan was reduced by harvesting, macroinvertebrate abundance was enhanced per unit macrophyte biomass[22]. In these two studies, lagarosiphon biomass was 12 fold greater in Lake Dunstan than Lake Wanaka, suggesting very dense beds provide poorer habitat for macroinvertebrates. It is also thought that lagarosiphon may reduce fish access to macroinvertebrate food[21], whereas harvested channels within large weed beds may enhance fish access and feeding[22].

Dense lagarosiphon beds restrict water movement and reduce light and may locally modify water chemistry. Lagarosiphon beds in an Irish lough were associated with accentuated diurnal fluctuations of dissolved oxygen and pH[14] and found to create progressively stressful conditions of high pH and low CO_2 content under experimental conditions[23]. Lagarosiphon beds in Lake Wanaka were found to be more productive (carbon fixation) than native vegetation in the comparable depth zone, with higher productivity again suggested for large weed beds in more nutrient enriched New Zealand lakes[21]. This productivity may contribute to the observation that dense lagarosiphon beds accumulate deep deposits of flocculent organic mud[14].

Lake Wanaka/Otago values at risk.

Lake Wanaka is held as one of the more pristine water bodies of New Zealand. It is included in the Regional Water Plan (1 A Schedule of natural values) for scenic values (unmodified lake level, water quality and colour) and significant indigenous vegetation (rare association of aquatic plants)[24]. Widespread development of lagarosiphon is likely to impact on the aesthetics of lake shorelines as the plant is capable of growing into dark-coloured, near-surface growths, which contribute to onshore drift and decomposing shoreline accumulations[20].

The high water transparency of Lake Wanaka supports internationally important examples of the deep-growing plants, charophytes and bryophytes[25]. The lake also has a high biodiversity of native submerged plants, which at 26 species represents approximately half the submerged plant species known from New Zealand (NIWA unpublished data). Impacts on these natural heritage values are to be expected if lagarosiphon expands.

Lake Wanaka is also highly valued as a boating and fishing destination with recent (summer 2015) estimates of 2000 pleasure craft utilizing the lake in one day[26]. Large beds of canopy-forming weeds are associated with depressed quantity and quality of boating, swimming and nearshore recreation[27]. Entanglement and drownings have been linked to invasive weed beds[28], while dense mats of weed provide good habitat for the snail hosts of parasites that cause 'swimmer's (duck) itch'[27], which has been recorded at Lake Wanaka. Direct lagarosiphon impacts on the recreational fishery of Lake Wanaka are uncertain but are likely mediated through physical exclusion of fish from areas of large, dense beds.

The cost of biodiversity loss following biological invasion often goes unvalued. However, of relevance is the New Zealand economic analysis study showing Waikato residents were willing to pay significant amounts to prevent exotic weed infestations in a local lake to protect indigenous biodiversity[29]. For example, the study revealed 'willingness to pay' of NZ$234 per regional household over 5 years to prevent *Hydrilla verticillata* (hydrilla) establishment (same family as lagarosiphon) and NZ$146 to avoid the loss of charophytes[29 30].

Similarly, economic estimates of weed impacts on recreation are rare. In one study of hydrilla on a Florida lake (108 km^2), recreational values at risk from hydrilla were estimated at US$857,000 annually[31]. The willingness to pay by users to preserve recreation where it was deemed at risk from invasive aquatic weeds was estimated at US$4.62 per person per day[31].

Also at risk from weed invasion are local property values. In an economic assessment comparisons between lakefront property values at US lakes with and without the presence of canopy-forming weed (*Myriophyllum spicatum*) showed invasion corresponded to a 19% decline in mean property values[32].

These examples suggest real economic costs are associated with the impacts of lagarosiphon on Lake Wanaka. However, the actual cost cannot be stated without specific analysis of the value of industries associated with lake quality and public perception of acceptable levels of degradation by the weed.

Beyond Lake Wanaka there are a large number of Otago lakes where lagarosiphon has not yet established. Flow-on risk from the lagarosiphon infestations at Lake Wanaka to these sites must also be considered. Nevertheless, the closer proximity of Lake Dunstan and Clutha River infestations may pose a greater threat to iconic Lake Wakatipu, which has special status under a Water Conservation Order[*].

As well as the current lagarosiphon control programme for Lake Wanaka there are similar initiatives for the adjacent Waitaki Catchment, Lake Dunstan and upper Kawarau River. The wider region would benefit from a collaborative approach between these programmes, shared information and learnings, and overall increases in public awareness.

[*] Included in Schedule 2 of the Water Conservation (Kawarau) Order 1997

5 Current lagarosiphon status in Lake Wanaka

To enable effective lagarosiphon management, Lake Wanaka has been divided into strategic management areas at two spatial scales. These comprise larger management zones, delineated by lines, which contain 48 Shoreline Management Units (Appendix B). A Containment Line between Sandspit Point and The Peninsula South delimits a northern Eradication Zone (Figure B-1). Southwards lies a Buffer Zone, which incorporates the Shoreline Management Units of Glendhu Shoreline, The Point, Ruby Island, and The Peninsula South (Figure B-2). Target Control Zones lie to the west, and to the south-east of the Buffer Zone delineated by Buffer Lines (Figure B-2).

On an annual basis the status of lagarosiphon at each shoreline unit is summarised into one of six weed density classes by the contractor undertaking control works. Lagarosiphon status as of June 2015 is represented in Figure B-3. This shows lagarosiphon was not detected from 17 of the 25 Shoreline Management Units in the Eradication Zone. Isolated single plants were recorded from the shorelines of Mineret Burn, Rumbling Burn, Colqhouns Coast, Mou Waho Island and the Peninsula West (Figure B-3). Mou Tapu Island had the same status but recorded one large lagarosiphon plant in March 2015. Roys Peninsula and Bishops Bay were described as having scattered plants with some drift fragments observed. Shoreline units in the Buffer Zone have a variable lagarosiphon status ranging from isolated single plants (The Peninsula South, Ruby Island) to large groups or patches of plants at Glendhu Shoreline. Considerable clearance of lagarosiphon by suction dredging along Glendhu Shoreline means a proportion of the shoreline is less infested than indicated. In the Target Control Zones several hundreds of metres of shoreline at Glendhu Bay, Fernburn, Sandspit and at Stevensons Island have also been reduced by management to the point where hand weeding may maintain them free of lagarosiphon. However, some highly infested areas remain.

In the 10 years since implementation of the 2005 Lagarosiphon Management Plan, significant progress has been made. Two southward adjustments of the Containment Line mean that eradication is now considered feasible along a much greater extent of shoreline. Currently, maintenance surveillance and hand weeding are the only actions required in the Eradication Zone, where the most recent suction dredging in the Zone was required in 2006 in West Wanaka Bay[33]. Advances in the Eradication Zone have meant that greater resources are now being directed within the Buffer Zone and Target Control Zones by undertaking suction dredging following successful herbicide outcomes.

6 Control techniques

Methodologies for lagarosiphon control differ in their effectiveness and outcomes, costs, advantages and disadvantages, with these considerations specific to the site and situation (Appendix C). Assessment of these methodologies against three key criteria of relevance to the Lake Wanaka situation identified four appropriate methodologies (Appendix D); these were hand weeding, suction dredging, herbicide (diquat) and bottom lining.

Hand weeding removes individual lagarosiphon plants. It is an appropriate method for weed eradication in situations where a target weed can be easily identified (e.g., sufficient water clarity) and is distributed at a low density of <125 shoots per 0.1 ha[34], or where patches do not exceed 1 m^2. It is not practical once infestations expand, as it becomes a very labour intensive method. Hand weeding has been used in the US[34], Ireland[5] and Lake Waikaremoana. In Lake Wanaka, hand weeding has been highly effective to remove re-colonising plants following suction dredging and achieved eradication of lagarosiphon, detected by the surveillance programme, from some shorelines north of the Containment Line.

It is vital to completely remove all viable plant material when hand weeding (e.g., avoiding shoot breakage, excavating root crowns) and the method requires experienced divers. Effective visual coverage for detection and subsequent removal of scattered plants in open areas of gradual slope can be difficult and may require demarcation of an underwater search grid (i.e., lines and marker buoys).

A **suction dredge** or diver-operated Venturi suction pump removes lagarosiphon and discharges uprooted plants into a floating barge or fine mesh collection bag[35] to be disposed of safely. This method is high cost, only feasible for moderate biomass beds in limited areas, is slowed by hard-packed sediments, and requires good underwater visibility[36]. Up to 20 days labour per ha is likely for dense weed beds and one of the major rate limiting steps is the time taken to navigate to and from targeted sites, and to off-load and dispose of bulky weed. Suction dredging can be effective for up to three years in lagarosiphon beds, however, it is unlikely to achieve weed eradication alone (without some follow-up hand weeding) because of recovery from any remaining weed fragments[37]. Suction dredging was used to eradicate submerged weed from a 610 m length of river in Texas, USA[38] and to remove a large lagarosiphon bed in Lake Waikaremoana.

In Lake Wanaka, suction dredging has been used since 1980 to remove outlier lagarosiphon colonies[39] and for public amenity areas like boat ramps and jetties, to minimize the risk of fragment transfer within the lake and to nearby uninfested water bodies. Combined with follow-up hand weeding, suction dredging has eradicated weeds from extensive shoreline areas of the lake. Nevertheless, at densely infested sites suction dredging is dependent on a successful herbicide treatment to reduce weed biomass to a level where dredging becomes feasible. If on-site disposal of weed is feasible by mulching and/or deep-water disposal (without the generation of large numbers of viable fragments), then suction dredging will become far more cost effective.

There are two **herbicides** registered for use in New Zealand freshwater; diquat and endothall. They are contact herbicides that desiccate and defoliate plant tissue that come into contact with the herbicide[40 41]. The herbicides are highly effective against lagarosiphon yet have far less effect, or no effect, on native submerged plants. The outcome of successful treatment is a substantial reduction in the standing biomass of weed beds, with control of lagarosiphon expected to last for a season or up to 1 year from treatment. However, with current use patterns neither herbicide is likely to eradicate lagarosiphon at sites in Lake Wanaka.

Diquat is a widely used herbicide[35] that is relatively fast acting[42]. The active ingredient is diquat dibromide, with a concentration of 1 mg per litre (i.e., a 1:100,000 dilution) recommended to control weeds. Diquat can be applied by boat using surface booms or subsurface injection via trailing hoses or booms. Helicopter application is appropriate for large areas under suitable weather conditions. Diquat is applied at a rate of 30 litres per ha water surface, regardless of water depth, with over 0.5 m depth further diluting applied diquat to <1 mg per litre [40]. However, weed control has been achieved with application through several metres depth, at extremely low concentrations, as long as a sufficient contact time with plant tissue is achieved. Diquat performance is best in dense weed beds that retain the herbicide for longer. Effectiveness can also be enhanced by the addition of gelling agents that help place the herbicide within the weed bed. Double application of the herbicide at half application rates is also thought to extend the contact time. Diquat efficacy is reduced in turbid water[43] or where plants are covered in organic matter or deposits of silt, which can rapidly bind the diquat. Therefore checks of plant and water conditions are a necessary step before proceeding with application.

Diquat has negligible risk to human health and aquatic biota at the concentrations applied to the aquatic environment[40]. It is rapidly absorbed by plants and it tightly binds (adsorbs) to both inorganic and organic compounds within the water and bottom sediments. This means diquat is available in the water column for a very short time-frame (minutes to hours). Adsorbed diquat has no residual toxicity, is not biologically active and is degraded slowly by microbial organisms within sediments. No accumulation of diquat could be detected in sediment at sites that have been regularly treated for decades[44].

The advantage of endothall over diquat is that it is not deactivated by turbid water or dirty plant surfaces. However, a much longer contact time is required for effective control. Eradication of lagarosiphon has been achieved in smaller water bodies using this herbicide[45]. Further research to evaluate endothall as a potential control tool in a large lake such as Lake Wanaka is required before this option could be recommended.

Placement of materials to cover weed beds and sediments is termed **bottom lining**, which operates by excluding light for submerged plant growth and by removing root access to substrates. This option is suitable for one-off site eradication, or to provide medium-term control (years) in reducing vegetation biomass. Bottom lining was previously trialled (c. 1992) in the entrance to Paddock Bay using silage polythene, but this proved difficult to lay and was not effective long-term due to sedimentation on top of the barrier and recolonization by lagarosiphon.

The outcome of bottom lining depends upon the extent of installation, the properties of the material used[46] and the degree of exposure to water movement. Too much water movement can remove the lining material, while high sedimentation rates can bury the lining enabling weed recolonisation. More recently, use of a new material, jute hessian, was found to be successful in controlling lagarosiphon in an Irish lough in as little as four months[46]. NIWA trials have also shown that denser hessian and coconut fibre could successful remove lagarosiphon within five months[47]. Jute hessian is biodegradable, lasting up to 10 months before beginning to disintegrate [46]. Another advantage of materials with an open weave is they allow sediment gases to escape, macroinvertebrate species to migrate between the sediments and water column, and for some native plants to grow through the mesh [46 476].

Limitations to use of bottom lining include spatial scale of application, although treatment of sites up to 5000 m² has proved possible[46]. Steep slopes or areas with numerous obstacles are difficult to bottom line and removal of high weed biomass is required prior to laying. Although linings can be weighed down by sand bags, rocks, or else pinned in place, they are susceptible to dislodgement in high wave energy environments. High rates of sedimentation will reduce effectiveness, with plant re-colonisation possible when sediment reaches a depth of 4 cm[48]. Trialling of new bottom lining materials in Lake Wanaka is required before their applicability can be confirmed for this lake environment.

Method selection is dependent on site characteristics (e.g., lagarosiphon biomass, site size, slope, sediment type) and the outcome sought. The appropriate method depends strongly upon the biomass of lagarosiphon being treated (Figure 3), with subsequent control outcomes dictating changes in future methods. For example, successful herbicide control of high biomass beds leads to other feasible control options (suction dredging, possible bottom lining). Thus an integrated combination of methods is required for Lake Wanaka.

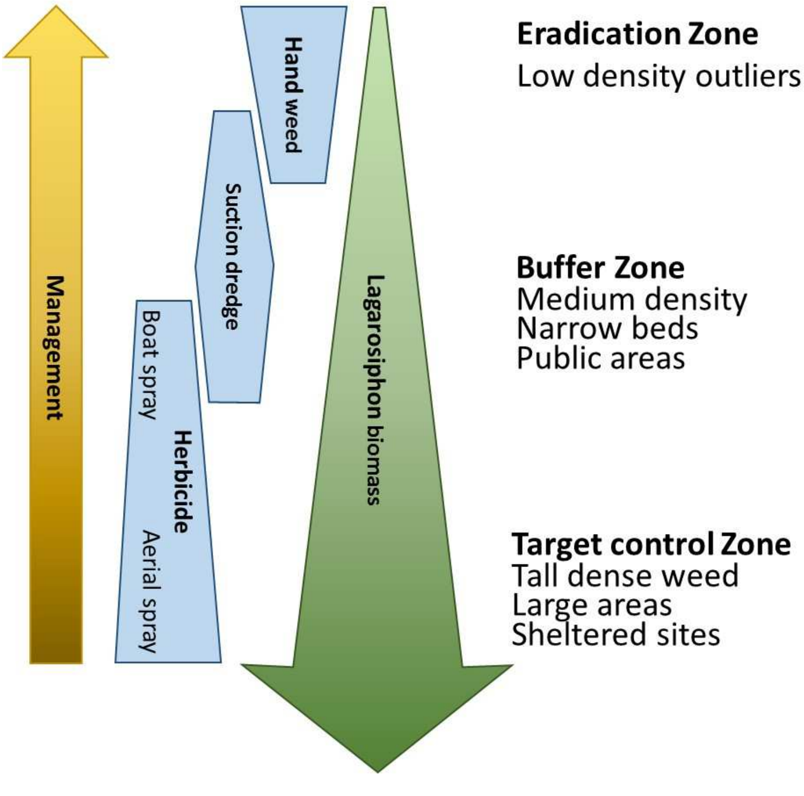


Figure 3: Relationship between feasible control method and lagarosiphon biomass. Right hand text aligns with the methods that are likely to be applicable in the management zones of Lake Wanaka. The directional arrow for management recognises that a shift in method use at a site occurs over time as biomass is reduced.

7 Suggested 2015/16 programme

Strategies and tactics to achieve the objectives in the immediate future are identified for each strategic management zone (Appendix A), via a higher level assessment of management priorities and intensity, and corresponding tactics (Figure 4). This approach assumes funding for the immediate year is retained at a similar or higher level.

In the **Eradication Zone,** shoreline units are assessed as low risk if there have been no previous lagarosiphon records and these areas require the lowest intensity of management (Figure 4). Sites with historical records of lagarosiphon indicate potential susceptibility to reinvasion and therefore are checked on a more frequent basis. Shorelines that have been recently cleared or are closer to large lagarosiphon infestations are of the highest risk and likely require regular, repeated management action (Figure 4).

This approach will reduce costs in the Eradication Zone but would need to be modified in the event of major incursion finds. Frequency of surveillance is critical for lagarosiphon control, given the potential for settled fragments to rapidly establish and contribute additional fragments in an area. The timing of fragment introduction to an area relative to scheduled surveillance dictates the likelihood of further spread and ease of removal. This is illustrated in Appendix F, where the potential generation of lagarosiphon shoot height over time can be seen under scenarios of no management or differing frequency of intervention. Reducing the time interval between surveillance can make the difference for intercepting incursions before fragmentation is likely (Appendix F).

Emphasis within the **Buffer Zone** is on achieving minimum biomass. This zone is close to large sources of lagarosiphon fragments from the Target Control Zones, with Buffer Zone management required to minimise subsequent contribution of fragments to the Eradication Zone.

Large advances in lagarosiphon clearance from shorelines will be sought for the western **Target Control Zone**. The focus on this zone is due to its spatial separation from the main lagarosiphon infestation in the south-east Target Control Zone, and the fact that Glendhu Bay is a major lake access and recreational area. Initially, the Glendhu Bay and Fernburn shoreline management units should be preferentially managed, with a subsequent northerly progression. The aim is to add these shorelines into the Buffer Zone. Removal of established weed beds along the exposed Glendhu foreshore has the potential to erode the substrates that have built up under lagarosiphon plants over time. This should reduce the habitat suitability for lagarosiphon and slow re-colonisation. A more problematic area for management is western Paddock Bay, where a wide littoral shelf and prime habitat for lagarosiphon will mean a longer period of effort is required to make gains here.

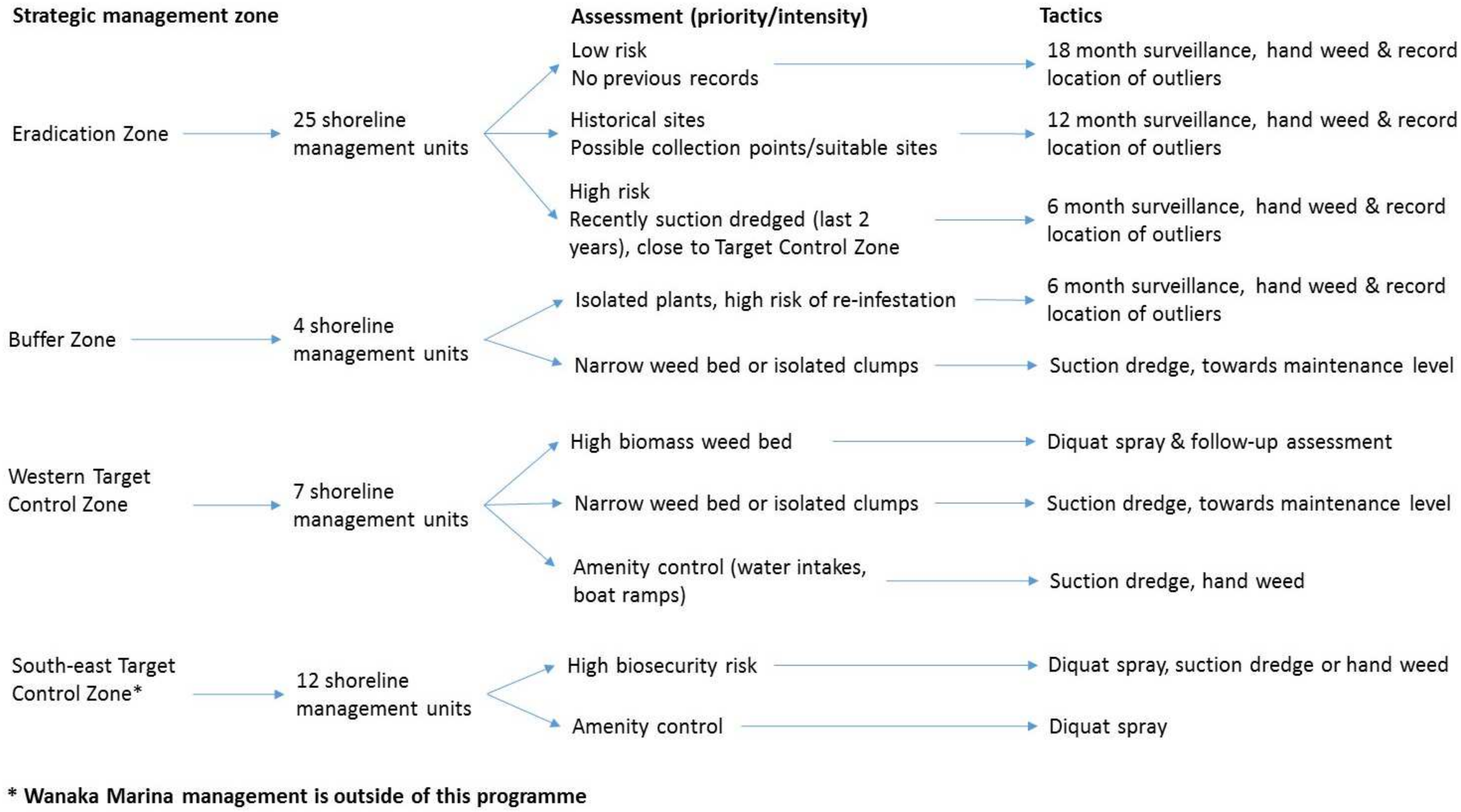
In the south-east Target Control Zone, priority sites that represent high biosecurity risk still need to be managed to maintain minimal biomass. Key areas for amenity protection should be prioritised and treated to minimise interference with activities.

Management of lagarosiphon in the **Wanaka Marina** falls outside of this programme. It is important to synchronise control activities wherever possible (e.g., diquat treatments), share findings on outcomes, and support the managers of the marina by providing information on any control advances.

Delivery of objectives, application of strategies and identification of site-specific tactics is aided by a Site Prioritisation Model (Appendix G). This tool was developed for Lake Wanaka by LINZ, NIWA and Enveco (environmental economics consultancy) to provide a transparent and objective assessment for budgetary allocation of lagarosiphon control amongst sites. Firstly, priorities of Shoreline Management Units (Appendix A) are assessed and scored against a number of criteria (Appendix G). The model then uses information on the site, such as the outcome sought, current lagarosiphon status, and most suitable control method to explore cost scenarios. Finally, the model allows costs and outcomes to be documented and likely future costs to be re-considered (Appendix G).

The timing of control works should continue to be guided by lake and meteorological conditions, together with avoidance of periods of peak lake usage for recreation. Herbicide applications are best scheduled for times of the year when lake levels are low, and suspended sediment in the water column and on plants is minimal. Hence optimal times for herbicide application are considered to be March and September. Lake water clarity is also a consideration for operator vision for surveillance, hand weeding and suction dredging.

Figure 4: Current scenario for management strategy and objectives for the 2015/16 year. Priorities and tactics will change as progress is made.



8 Key milestones

Here we identify operational milestones and their completion dates which will help benchmark progress towards Goals and Objectives (Figure 1).

1. All incursions beyond the Containment Line can be managed by hand weeding by 2025

Continued control of any incursions beyond the Containment Line by hand weeding alone signals that the surveillance frequency and removal efficiency is sufficient in the Eradication Zone and that gains made in this area are being maintained (see Objective 1).

2. Target Control Line shifts to Fernburn Point by 2020

Currently the Target Control Line runs from Sandspit Point to the Glendhu shoreline (Figure B-2). Moving this line to run from Sandspit Point to the Fernburn shoreline will incorporate Glendhu Bay into the Buffer Zone (and ultimately the Eradication Zone). This will involve the clearance of larger weed beds within a 3.5 km stretch of shoreline of Glendhu Bay, to the point where low level effort is required for maintaining minimal lagarosiphon biomass. Some progress has been made to date. The completion date within five years is challenging, but achievable.

3. An additional ten kilometres of shoreline is managed by surveillance and hand weeding by 2025

Surveillance and hand weeding is lower cost per unit shoreline than suction dredging. Advances in weed bed clearance by suction dredging in priority areas will free up budget to make further advances in other areas.

4. At least one new control tool is evaluated, and adopted if appropriate, by 2020

Scientific evaluation of additional control methodologies not currently used will be completed under Lake Wanaka conditions (e.g. jute matting, mulching and deep-water disposal, endothall, new emerging technologies). If validated, the tool(s) will be integrated in the control programme.

5. Progress is demonstrated in a five-year programme review in 2020

Critical review of lagarosiphon status relative to current (2016) status, as well as milestone completion after five years, will clearly show progress of the programme.

6. A media press release communicates progress in 2020

A 5-year review represents opportunities for positive media messages on progress and achievements from the programme. Coverage will be achieved in the top news outlets for the local area.

7. Funding is secured beyond the 2015 contributors and/or budget by 2025

Currently (2016), LINZ provide the majority of the budget for lagarosiphon control in Lake Wanaka, with additional contributions from ORC, QLDC and an anonymous donor (2015-2019). This funding base represents a potential risk to the programme (see Section 10). Greater funding contributions by a range of agencies or additional sponsors will provide greater security for the control programme.

9 Monitoring and plan revision

Currently an annual planning process is followed to determine the control works at Lake Wanaka sites (Figure 5). This enables the process to be adaptive, responding to progress as it is made, realigning subsequent priorities, and addressing any arising issues. The first step is an inspection of previous control and outcomes to date undertaken by LINZ biosecurity service partner, Boffa Miskell, together with NIWA, which also involves input from the contractor. An annual programme is then developed based on progress, agreed priorities and available budget. The annual programme is developed in two parts to provide some flexibility in management planning, allowing for changed priorities according to progress, and for matching management actions with the best time of the year for works. An assessment of progress and the proposed programme of works is presented to the LWLM Committee in August and February. This provides an opportunity for agency input and approval. Control works are then scheduled and contractors report on progress to Boffa Miskell.

Over the longer-term, a five year review process is integrated into the lagarosiphon management programme. This review process will fall due in 2020. At this time the LWLM Committee will measure progress against the identified key milestones (Section 8). New milestones may be added depending on progress. The six objectives (Section 2.3) will be re-visited to ensure their continued relevance for achieving the higher goals (Section 2.2). This process will result in agreed amendments to the 10 Year Lagarosiphon Management Plan. The 5-year review process should also provide an opportunity for public statement about the status of the programme and achievements.

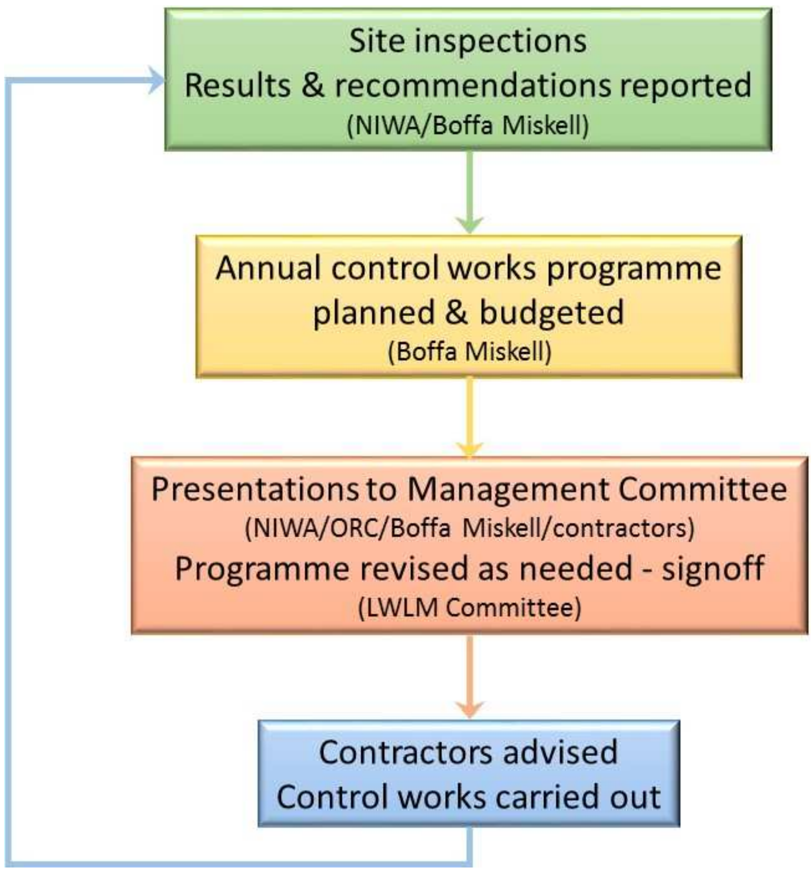


Figure 5: Annual process of planning and review that sets the programme of control works.

10 Risks

We recognise potential risks and barriers to the progress on objectives (Section 2.2) and achievement of milestones (Section 8). As far as possible, these are considered below and possible mitigation measures are identified.

Some risks/barriers have been experienced during past management of lagarosiphon at Lake Wanaka and this history illuminates possible future challenges. For example, prior to 2005 lagarosiphon management suffered from changing agency responsibilities, shifting goals, and variable and inadequate funding (Appendix E). Policy changes saw the withdrawal of some funding. Herbicide use was threatened by an anti-chemical campaign in 2004. Some of these risks still exist today.

Funding loss

Currently the funding base for lagarosiphon control is primarily from central government administered by LINZ. Contributions from local rate-base sources are minimal, yet it could be argued that the local economy has the most to lose from lagarosiphon expansion. Reliance on one source of funding has the associated risk of re-allocation as agency priorities change (e.g., a new emerging biosecurity threat on crown land). In the event of changing responsibilities or focus by LINZ, it is conceivable that the budget may be reduced. Key Milestone 7 recognises this threat, but specific actions to widen the funding base is beyond the scope of this report.

Adverse public perceptions

Opposition from even small sectors of the community can result in a restriction on control tools and adverse publicity for the programme. A proactive communications strategy (Key Milestone 6) to inform and engage with the public is likely to moderate community support for extreme views.

Lake conditions constrain works

There is potential for a prolonged period of poor water quality (e.g., a turbid event) or weather to limit the application and effectiveness of control works in Lake Wanaka. Contingency to accommodate such events should include transfer of budget from one year to the next, as well as between each half of the annual programme.

11 Conclusion

This strategic review of the previous (2005) Lagarosiphon Management Plan provides a long-term (ten year), shared vision for lagarosiphon control works in Lake Wanaka. The plan will be implemented by lead agency Land Information New Zealand (LINZ) and the Lake Wanaka Lagarosiphon Management (LWLM) Committee. This document will also help in communications between LINZ biosecurity service partner, Boffa Miskell, science advisers (NIWA) and contractors undertaking control works.

12 Acknowledgements

This revised management plan benefited from discussions with David Mole (LINZ), Marcus Girvan (Boffa Miskell), contractors and the LWLM Committee. Fleur Matheson (NIWA) contributed Figure 5 and Appendix G.

13 Glossary of abbreviations and terms

Containment	Containing pests within a specified (usually restricted) range.
Control	Reduction of impacts through management action.
Eradication	The permanent removal of the entire pest population at a site.
Exclusion	Exclusion of pests from an unoccupied range.
Pathways	The method or route by which pests spread.
Vectors	The mechanism by which pests spread.

Appendix A Definitions of terms

The following definitions used in the Goals are drawn from the Regional Policy Statement for Otago (*also defined by Section 2 of the Resource Management Act 1991).

- **Amenity Values*** - Those natural or physical qualities and characteristics of an area that contribute to people's appreciation of its pleasantness, aesthetic coherence, and cultural and recreational attributes
- **Aesthetic Value** - A value associated with the visual quality or the appreciation of the inherent visual quality of an element in the built or natural environment.
- **Heritage Site** - Any place or object of special cultural, architectural, historical, scientific, ecological or other interest, or of special significance to the tangata whenua for spiritual, cultural or historical reason
- **Intrinsic Values*** - In relation to ecosystems, means those aspects of ecosystems and their constituent parts which have value in their own right, including:

  (a) Their biological and genetic diversity; and
  (b) The essential characteristics that determine an ecosystem's integrity, form, functioning, and resilience.

Appendix B Strategic Management areas

Figure B-1: Map of Lake Wanaka showing strategic and shoreline management units in the Eradication Zone north of the Containment Line. Twenty-five shoreline management units are differentiated by alternating shades of red. See Figure B-2 for the Buffer Zone and Target Control Zones.

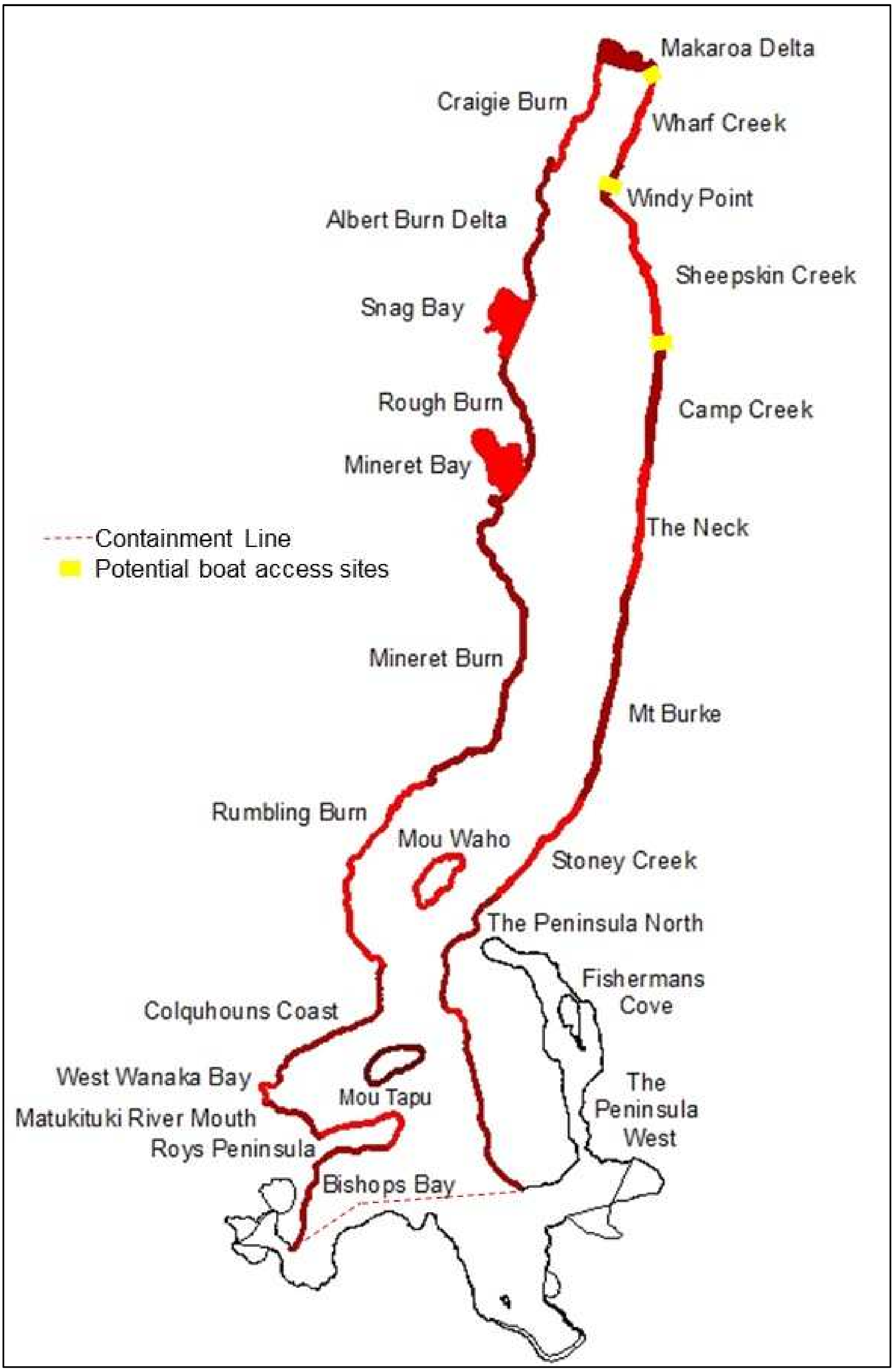


Figure B-2: Map of Lake Wanaka showing strategic and shoreline management units for the Buffer Zone and Target Control Zone. Buffer Lines and Containment Lines separate the Eradication Zone to the north (see Figure A-1), the Buffer Zone to the south, and the western and south-eastern Target Control Zones. Twenty-three shoreline management units and Wanaka Marina are differentiated by alternating shades of green.

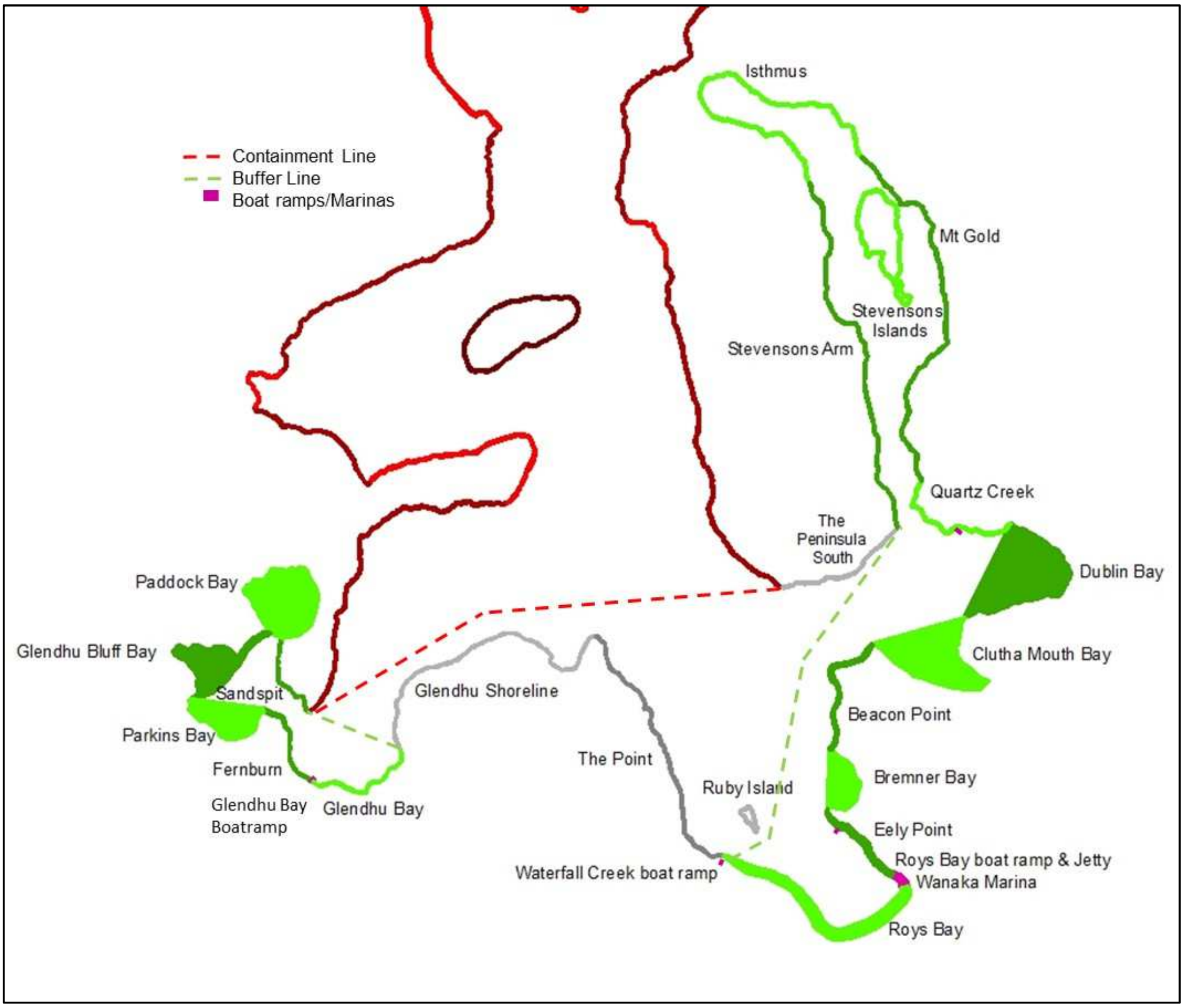
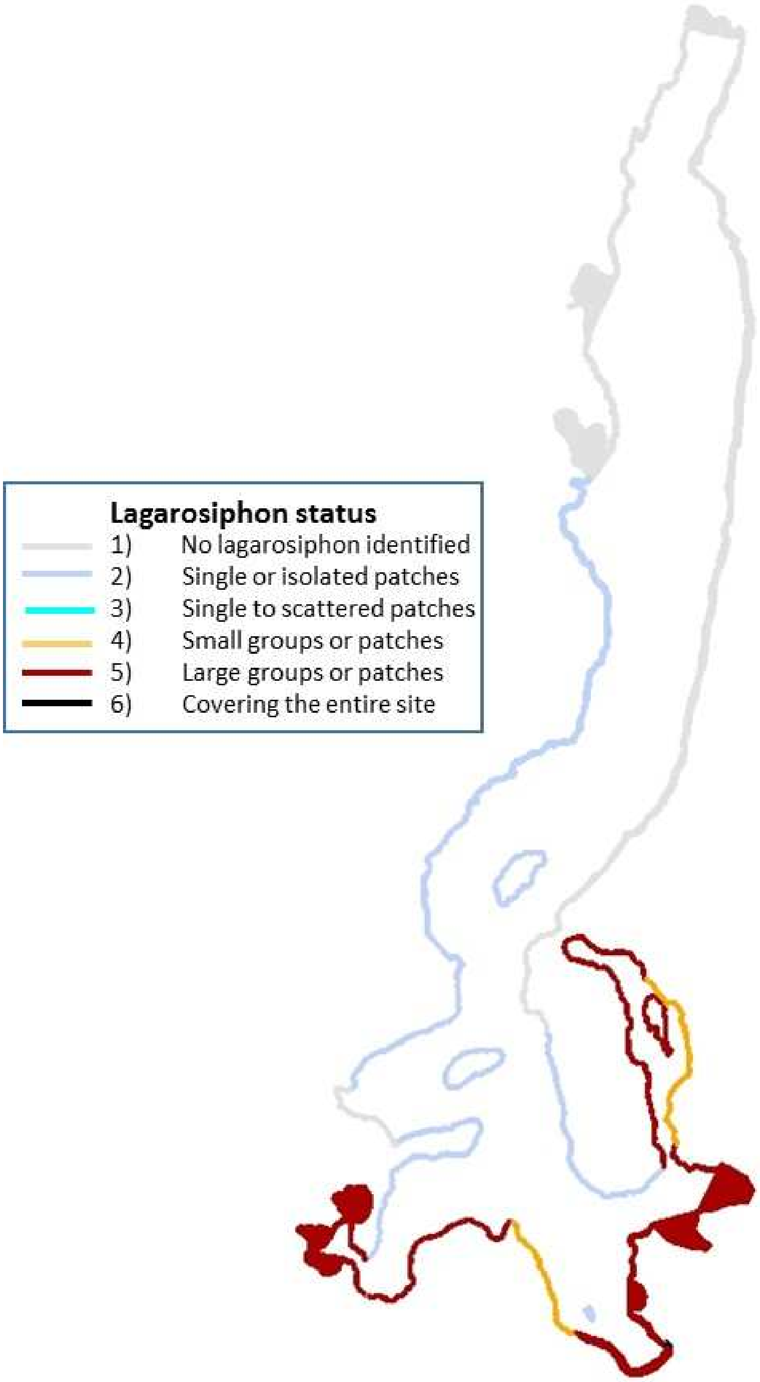


Figure B-3: Status of lagarosiphon density for the 48 shoreline management units in Lake Wanaka, May 2015.



Appendix C Review of potential control methodologies

Table 1: Control methodologies that may be applicable to lagarosiphon, summarising likely effectiveness, relative cost (by application), advantages and disadvantages.

Method	Effectiveness	Relative cost	Advantages	Disadvantages
Hand removal	Highly effective given small isolated plants & experienced divers Can achieve site eradication	High cost as labour intensive ($10k per ha)	Immediate removal, no adverse effects, easily integrates with surveillance activities	Limited to isolated plants or clumps ≤1m², needs good water clarity & low surrounding vegetation for detection. Small plants may not be detected until they have grown larger
Suction dredge	Highly effective at reducing biomass in medium size patches/narrow beds	High cost as labour intensive	Immediate removal, fragments well contained, but follow-up required, selective therefore few adverse effects	Debris, rocky or hard packed substrates reduce effective removal & increase cost
Weed harvester	Can remove c. 80% of biomass if depth ≤ 2m & gradient suitable	Machinery outlay is the major cost (c. $200k)	Large areas can be controlled quickly for amenity benefit	Limited to cut of ≤2 m depth, rapid regrowth, non-selective, large release of fragments, machinery difficult to decontaminate therefore usually dedicated to a waterbody
Rototiller	Can provide >6 months control over 1.5 to 4 m depth under suitable depth and sediment conditions[49] [37].	Machinery outlay is the major cost	Deep rototilling can provide longer control (but is more expensive)	Consent required, non-selective, poorer control on harder substrates or shallow rototilling, large release of fragments, machinery difficult to decontaminate
Diquat herbicide	Capable of removing >90% of biomass, control lasts at least a growth season, unlikely to achieve site eradication	Moderate cost $1.6k per ha (permitted activity)	Large areas can be controlled quickly, slows recovery as plants reallocate reserves to undamaged buds, moderately selective, few adverse effects	Deactivated in turbid water, lake currents may remove or dilute herbicide, woody stems & root crowns highly resistant

Method	Effectiveness	Relative cost	Advantages	Disadvantages
Endothall herbicide	Capable of removing >90% of biomass, control lasts at least a growth season, unlikely to achieve site eradication	Moderate to high cost (EPA approval required)	Not deactivated in turbid water, partially selective, few adverse effects, aqueous or pellet formulations	Needs a long contact time, suitable for small waterbodies or enclosed areas, use requires additional NZEPA approvals
Dichlobenil herbicide	Up to 100% control in suitable sites[5]		Not registered for aquatic use in New Zealand	
Grass carp	Capable of weed eradication on whole lake basis within a few years	Very high cost based on containment structure, fish numbers required & approvals process	Can eradicate target species	Non-selective control, with adverse effects likely on native plants, containment required (prevent escape to Clyde River), browsing at low temperatures <16°C may limit effectiveness
Classical biocontrol (host-specific insect)	Suppression of high biomass possible, will not achieve site eradication	Development & testing costs high (national funding level) but release costs likely to be low	Potentially self-sustaining populations achieved	Not yet available, uncertain outcome over effectiveness
Mycoherbicide (inundative biocontrol)	Capable of removing >90% of biomass, control lasts at least a growth season, site eradication possible	Development & testing costs high	Impact is localised and contained to the treatment area	Not yet available, uncertain outcome over effectiveness

Method	Effectiveness	Relative cost	Advantages	Disadvantages
Water drawdown	Desiccation or freezing can reduce biomass temporarily, unlikely to eradicate	Construction of a water level control structure would be extremely costly	Relatively easy to carry out if water level control structure (e.g., dam) and any necessary consents for drawdown already in place.	Requires water level control structure, large, sustained fluctuation required, large adverse effects (erosion, loss of habitat) Would contravene the Lake Wanaka Preservation Act 1973
Bottom lining (new biodegradable materials)	Can eradicate outlier colonies, amenity control in limited areas, medium-term control (up to a few years), control in 4-5 months[46 47].	High cost as labour intensive ($30,000 per ha)	New biodegradable materials are easier to lay, may act as geotextile in stabilising sediments when weed removed and facilitate native plant recovery	Requires consent, questionable feasibility for areas >5000 m², requires reduction of weed biomass first, sedimentation allows re-colonisation of area, lining can be dislodged by wave/currents,

Appendix D Selection of control methodologies against criteria

Table 2: Assessment of potential control methodologies for use in Lake Wanaka against key criteria.

Method	Technology is available in New Zealand	Suitable for sensitive areas where fragment generation is a risk	Feasible given budgetary limitations of the programme
Hand removal	yes	yes	yes
Suction dredge	yes	yes	yes
Bottom lining	Yes	yes	yes
Diquat	yes	yes	yes
Endothall	yes	yes	?
Weed harvester	yes	no	no
Rototiller	yes	no	yes
Dichlobenil	no	yes	yes
Grass carp	yes	yes	no
Classical biocontrol	no	?	Likely yes
Mycoherbicide	Under development	yes	?
Water drawdown	NA	NA	no

Appendix E History of lagarosiphon management in Lake Wanaka

An outline of the main events in the management of lagarosiphon in Lake Wanaka to date.

1972: Lagarosiphon reported from Roys Bay

1973: 3.5 km of shoreline infested, nuisance in marina

1974: Diquat treatment commenced, eradication goal revised to containment, multi-agency collaboration

1976: NZED funded 1st Lm removal efforts. Objective was to protect future welfare of Lake Dunstan.

1977: Lagarosiphon at Ruby & Stevensons Island, Glendhu, Parkins & Dublin Bay

1978: Ministry of Agriculture & Fisheries begin as technical advisors

1979: Lands & Survey begin management, eradication still seen as feasible, hand weeding of outlier colonies

1980: Suction dredging & hand weeding used, with bottom lining trialled

1982: Lagarosiphon sale in nursery/aquarium trade prohibited

1987: Department of Conservation begin management, diquat, suction dredging & hand weeding used

1988: Electricorp (ex NZED) funding ceased as lagarosiphon became unmanageable in the Clutha River

1991: Funding withdrawal meant no management for 9 months after period of inconsistent funding

1993: Regional Pest Management Strategy (RPMS) developed by Otago Regional Council, identifies lagarosiphon containment area in Lake Wanaka

1998: Land Information New Zealand (LINZ) resume management with Opus International as sub-contractors

1998: Biomass suppression, containment & eradication of outlier colonies still a focus

2000: New control technologies trialled on major weed beds developing in Paddock Bay

2001: LINZ contract Landward Management Ltd, policy shift to inter-waterbody containment & amenity control only

2003: Increase in infested shoreline prompts multi-agency workshop to discuss concerns & solutions

2004: MOU developed for multi-agency management team, LINZ lead agency, government funding doubled

2004: Public campaign against diquat use

2005: Community criticism of 2004/05 interim control programme

2005: 10 year management plan prepared by Lake Wanaka Lagarosiphon Management Team, adopted 2005/06, Otago RPMS recognises 10 year plan

2005: Policy shift to in-lake protection of biodiversity, natural heritage & amenity values, as well as containment

2007: Designated zones for containment (eradication), buffer (reduce biomass) & target control (strategic & amenity)

2009: LINZ appoint Boffa Miskell to manage control operations

2009: Containment line shifted south, additional 2 km shoreline where eradication feasible

2010: Site Prioritisation Model developed by LINZ & NIWA, for allocating resources to sites based on multiple criteria

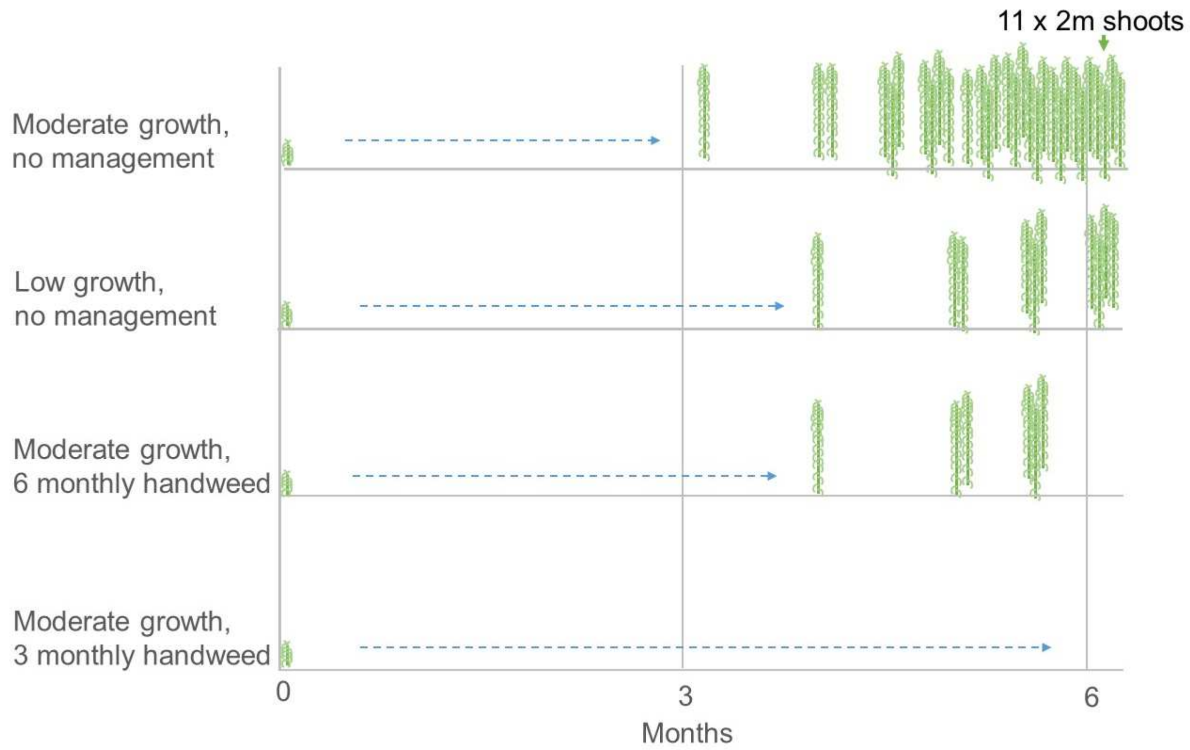
2013: Containment line shifted south, additional 6 km shoreline where eradication feasible

2015: First private funding contribution to the control programme received

Appendix F Lagarosiphon growth scenarios

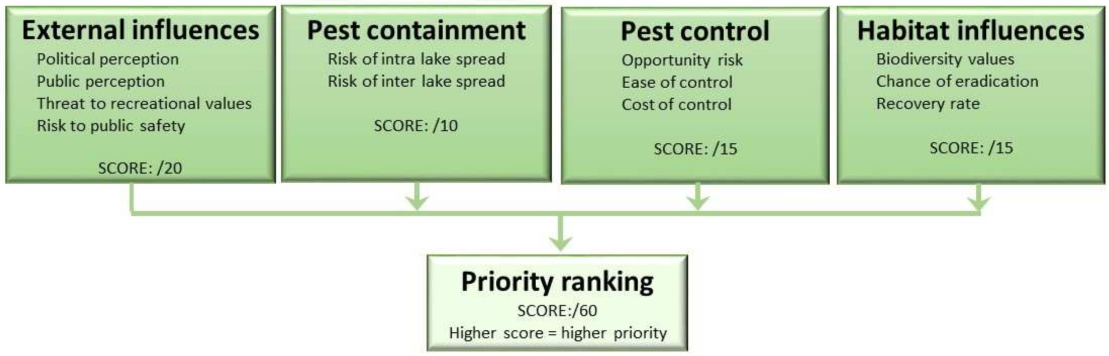
Surveillance frequency and timing is important relative to the establishment of a new fragment. The aim is to find and remove a plant before it generates further fragments. Scenarios of lagarosiphon stem growth, assuming moderate or low growth rate, and the effect of frequency of hand weeding are considered here.

Plants start as a 0.1 m long fragments and expansion is shown as the number of 2m length shoots, under the worst case scenario of incomplete removal by hand weeding. Growth rate is based on modest values[50] of 0.02 to 0.03 proportional length increase day^{-1}, with higher values of up to 0.063 day^{-1} also reported [51]. In this example, hand weeding every 3 months would effectively prevents the formation of 2 m tall shoots that are prone to fragmentation, whereas 6 month frequency might allow plant biomass to develop if removal was not efficient. Therefore under limited resourcing, there should be a compromise between the frequency of surveillance and hand weeding and risk of fragment establishment.

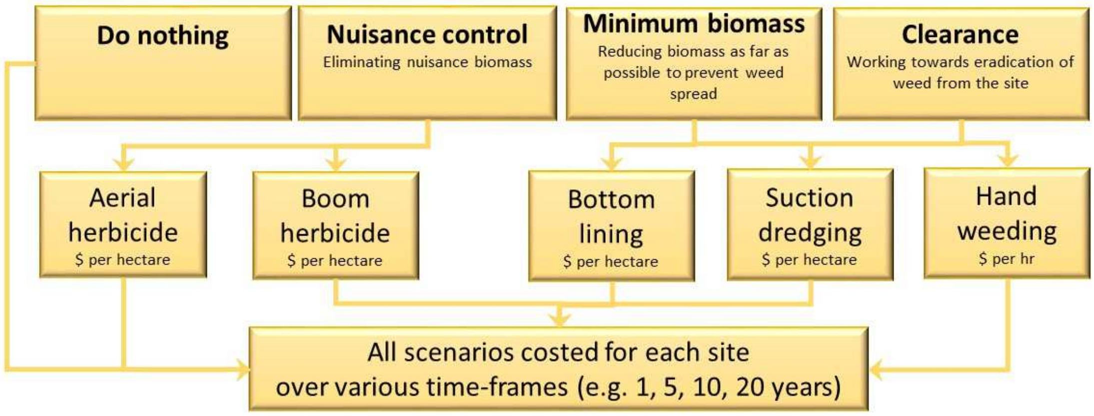


Appendix G Site Prioritisation Model

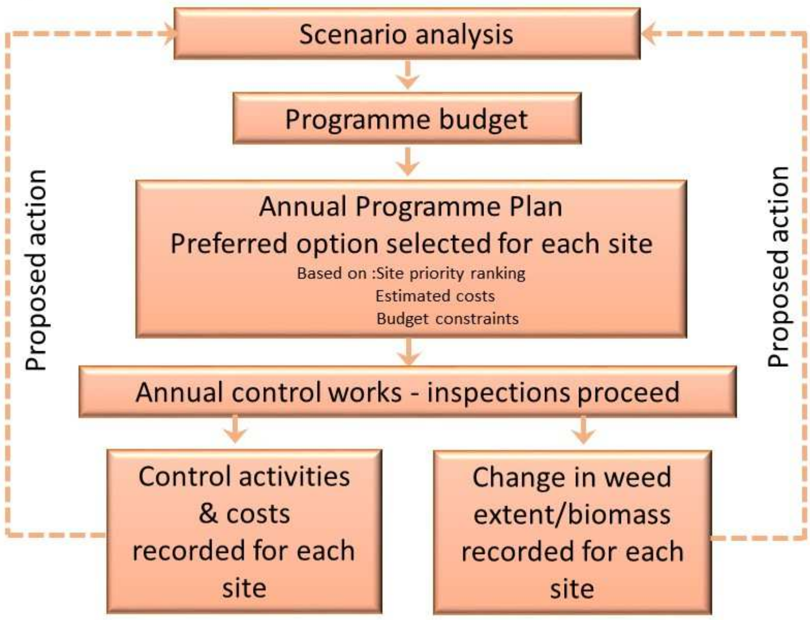
1. Site prioritisation



2. Site control options & costs



3. Planning and evaluation



14 References

[1] Lake Wanaka Lagarosiphon Management Team (2005) A 10 year lagarosiphon management plan for Lake Wanaka: 2005-2015: 25. http://www.orc.govt.nz/Documents/Content/Information%20Services/Pests/PLants/lagarosiphon_10yr_plan.pdf

[2] Coffey, B.T., Clayton, J.S. (1988) New Zealand waterplants. *A guide to plants found in New Zealand Freshwaters.* Ruakura Agricultural Centre.

[3] Triest, L. (1991) Isozymes in Lagarosiphon (Hydrocharitaceae) populations from South Africa: the situation in dioecious, but mainly vegetatively propagating weeds. In: Triest, L. (Ed). Isozymes in Water Plants. *Opera Botanica Belgica,* 4: 71-86.

[4] Sculthorpe, C.D. (1967) *The Biology of Aquatic Vascular Plants*. Edward Arnold Publishers, London.

[5] Caffrey, J., Millane, M., Evers, S., Moran, H. (2011) Management of *Lagarosiphon major* (Ridley) Moss in Lough Corrib - A review. Biology and Environment. *Proceedings of the Royal Irish Academy,* Section B, 111B(3): 205-212.

[6] Matthews, J., Beringen, R., Collas, F.P.L., Koopman, K.R., Odé, B., Pot, R., Sparrius, L.B., van Valkenburg, J.L.C.H., Verbrugge L.N.H., Leuven R.S.E.W. (2012) *Knowledge document for risk analysis of the non-native curly waterweed (Lagarosiphon major) in the Netherlands*. http://www.q-bank.eu/Plants/Controlsheets/KD_Lagarosiphon_final20121031.pdf

[7] http://www.issg.org/

[8] Riis, T., Lambertini, C., Olesen, B., Clayton, J.S., Brix, H., Sorrell, B.K. (2010) Invasion strategies in clonal aquatic plants: Are phenotypic differences caused by phenotypic plasticity or local adaptation? *Annals of Botany,* 106(5): 813-822.

[9] Johnstone, I.M., Coffey, B.T., Howard-Williams, C. (1985) The role of recreational boat traffic in interlake dispersal of macrophytes: A New Zealand case study. *Journal of Environmental Management*, 20: 263-279.

[10] Getsinger, K.D., Dillon, C.R. (1984) Quiescence, growth and senescence of *Egeria densa* in Lake Marion. *Aquatic Botany*, 20: 329-338.

[11] Compton T.J., de Winton, M., Leathwick J.R., Wadhwa, S. (2012) Predicting spread of invasive macrophytes in New Zealand lakes using indirect measures of human accessibility. *Freshwater Biology,* 57: 938–948, doi:10.1111/j.1365-2427.2012.02754.x.

[12] Champion P.D., Clayton J.S. (2000) Border control for potential aquatic weeds. Stage 1—Weed risk model. *Science for Conservation 141.* Wellington, New Zealand, Department of Conservation.

[13] de Winton, M.D., Champion, P.D., Clayton, J.S., Wells, R.D.S. (2009) Spread and status of seven submerged pest plants in New Zealand lakes. *New Zealand Journal of Marine & Freshwater Research*, 43: 547–561.

[14] Caffrey, J., Acevedo, S. (2007) Status and Management of *Lagarosiphon major* in Lough Corrib 2007. http://www.fisheriesireland.ie/invasive-species-1/151-status-and-management-of-lagarosiphon-major-in-lough-corrib-2007-1/file

[15] Howard-Williams C., Davies, J. (1988) The invasion of Lake Taupo by the submerged water weed *Lagarosiphon major* and its impact on the native flora. *New Zealand Journal of Ecology,* 11: 13-19.

[16] ORC (2009a) *Pest Management Strategy for Otago 2009.* http://www.orc.govt.nz/Publications-and-Reports/Regional-Policies-and-Plans/Regional-Pest-Management-Strategy/

[17] ORC (2009b) *Operational Plan for the Pest Management Strategy for Otago*: 6. http://www.orc.govt.nz/Publications-and-Reports/Regional-Policies-and-Plans/Regional-Pest-Management-Strategy/

[18] Rattray, M.R., Howard-Williams, C., Brown, J.M.A. (1994) Rates of early growth of propagules of *Lagarosiphon major* and *Myriophyllum triphyllum* in lakes of differing trophic status. *New Zealand Journal of Marine and Freshwater Research,* 28: 235-241.

[19] Cavalli, G., Riis, T., Baattrup-Pedersen, A. (2012) Bicarbonate use in three aquatic plants. *Aquatic Botany,* 98: 57-60.

[20] Clayton, J.S., de Winton, M., Wells, R.D.S., Tanner, C.C., Miller, S.T., Evans-McLeod, D. (1989) The aquatic vegetation of 15 Rotorua lakes. *Aquatic Plants Section*. Ministry of Agriculture and Fisheries: 101.

[21] Kelly, D.J., Hawes, I. (2005) Effects of invasive macrophytes on littoral-zone productivity and foodweb dynamics in a New Zealand high-country lake. *Journal of the North American Benthological Society*, 24(2): 300-320.

[22] Bickel, T.O., Closs, G.P. (2009) Impact of partial removal of the invasive macrophyte *Lagarosiphon major* (Hydrocharitaceae) on invertebrates and fish. *River Research and Applications*, 25(6): 734-744.

[23] James, C.S., Eaton, J.W., Hardwick, K., (1999) Competition between three submerged macrophytes, *Elodea canadensis* Michx, *Elodea nuttallii* (Planch.) St John and *Lagarosiphon major* (Ridl.) Moss. *Hydrobiologia,* 415: 35–40.

[24] ORC (2014) *Regional Plan: Water for Otago*. http://www.orc.govt.nz/Publications-and-Reports/Regional-Policies-and-Plans/Regional-Plan-Water/

[25] de Winton, M.D., Beever, J.E. (2004) Deep-water bryophyte records from New Zealand lakes. *New Zealand Journal of Marine and Freshwater Research*, 38: 329-340.

[26] http://www.odt.co.nz/news/queenstown-lakes/328829/boating-alarm-sounded

[27] Eiswerth M.E., Donaldson S.G., Johnson W.S. (2000) Potential environmental impacts and economic damages of Eurasian watermilfoil (*Myriophyllum spicatum*) in western Nevada and northeastern California. *Weed Technology*, 14: 511–518.

[28] Getsinger K., Dibble E., Rodgers, J.H., Spencer D. (2014) *Benefits of controlling nuisance aquatic plants and algae in the United States*: 12. http://www.cast-science.org/download.cfm?PublicationID=282524&File=1030b3a54ebea7b19997c7d3a20702ea2c5TR

[29] Bell, B., Yap, M., Cudby C. (2009) Assessing the marginal dollar value losses to a freshwater lake ecosystem from a hypothetical aggressive weed incursion. Report to Biosecurity New Zealand on valuing the freshwater environment. *Report to Biosecurity New Zealand.* http://www.nimmo-bell.co.nz/pdf/forst/WP10Freshwatertechreportfinal.pdf

[30] WRA (2014) http://www.waikatoriver.org.nz/wp-content/uploads/2014/09/32-Non-Market-Values.pdf

[31] Bell, F.W., Bonn, M.A. (2004) Economic Sectors at Risk from Invasive Aquatic Weeds at Lake Istokpoga, Florida. The Bureau of Invasive Plant Management, Florida Department of Environmental Protection, Tallahassee, Florida. http://www.aquatics.org/pubs/istokpoga.pdf

[32] Olden, J.D., Tamayo, M. (2014) Incentivizing the public to support invasive species management: Eurasian milfoil reduces lakefront property values. *PLoS One,* 9(10): e110458. doi:http://dx.doi.org/10.1371/journal.pone.0110458

[33] Clayton, J. (2006) Lake Wanaka inspection September 2006. *NIWA Client Report* HAM2006-142, prepared for LINZ.

[34] Bellaud, M.D. (2009) Cultural and physical control of aquatic weeds. Chapter 6. In: Gettys, L.A., Haller, W.T., Bellaud, M. (Eds*). Biology and control of aquatic plants, a best management practices handbook.* Aquatic Ecosystem Restoration Foundation, Georgia, USA.

[35] Clayton, J.S. (1993) Resource evaluation and operational programme for lakeweed: the Upper Clutha and Kawarau catchment areas. *NIWA Client Report.*

[36] Champion, P.D., Clayton, J.S., Rowe, D. (2002) *Lake Managers' Handbook*. Alien Invaders. Ministry for the Environment: 444.

[37] Wells, R.D.S., Clayton, J.S., Schwarz, A.M., Hawes, I., Davies-Colley, R. (2002) Mighty River Power aquatic weeds: issues and options. *NIWA Client Report* MRP00502.

[38] Alexander, M.L., Doyle, R.D., Power, P. (2008) Suction dredge removal of an invasive macrophyte from a spring-fed river in Central Texas, USA. *Journal of Aquatic Plant Management*, 46: 184–185.

[39] Wells, R.D.S., Clayton, J.S. (2005) Mechanical and chemical control of aquatic weeds: costs and benefits. Chapter 208. In: Pimentel D. (Ed). *Encyclopaedia of Pest Management*. CRC Press 2002. http://www.crcnetbase.com/doi/abs/10.1201/NOE0824706326.ch208

[40] Clayton, J., Severne, C. (2005) Review of diquat reports of relevance to iwi values in Lake Karapiro. *NIWA Client Report:* HAM2005-136, prepared for Environment Waikato: 10. http://www.waikatoregion.govt.nz/PageFiles/5207/tr06-03.pdf

[41] MacDonald, G.E., Querns, R., Shilling, D.G., McDonald, S.K., Bewick, T.A. (2002) Activity of endothall on hydrilla. *Journal of Aquatic Plant Management*, 40: 68-71.

[42] Cassidy, K., Rodgers, J.H. (1989) Response of hydrilla (*Hydrilla verticillata* (L. f) Royle) to diquat and a model of uptake under nonequilibrium conditions. *Environmental Toxicology and Chemistry,* 8: 133-140.

[43] Hofstra, D.E., Clayton, J.S., Getsinger, K.D. (2001) Evaluation of selected herbicides for the control of exotic submerged weeds in New Zealand: II. The effects of turbidity on diquat and endothall efficacy. *Journal of Aquatic Plant Management,* 39: 25–27.

[44] HortResearch (2001) Pesticide Residue Report No. 186. *National Institute of Water and Atmospheric Science (NIWA) Technical Report.*

[45] Wells, R.D.S., Champion, P.D., Clayton, J.S. (2014) Potential for lake restoration using the aquatic herbicide endothall. Published Proceedings of the 19th Australasian Weeds Conference, pg 143-146.

[46] Caffrey, J.M., Millane, M., Evers, S., Moron, H., Butler, M. (2010) A novel approach to aquatic weed control and habitat restoration using biodegradable jute matting. *Aquatic Invasions*, 5(2): 123-129.

[47] Hofstra, D.E., Clayton, J.S. (2012) Assessment of benthic barrier products for submerged aquatic weed control. *Journal of Aquatic Plant Management,* 50: 101-105.

[48] Laitala, K.L., Prather, T.S., Thill, D., Kennedy, B., Caudill, C. (2012) Efficacy of benthic barriers as a control measure for Eurasian watermilfoil (*Myriophyllum spicatum*). *Invasive Plant Science and Management,* 5: 170–177.

[49] Clayton, J., Wells, R., Champion, P., Blair, N. (2000) Rototilling and alternative options for control of *Lagarosphon major* in Paddock Bay, Lake Wanaka. *NIWA Report* 78, Hamilton: 12.

[50] Stiers, I., Njambuya, J., Triest, L. (2011) Competitive abilities of invasive *Lagarosiphon major* and native *Ceratophyllum demersum* in monocultures and mixed cultures in relation to experimental sediment dredging. *Aquatic Botany,* 95(2): 161-166.

[51] James, C.S., Eaton, J.W., Hardwick, K. (2006) Responses of three invasive aquatic macrophytes to nutrient enrichment do not explain their observed field displacements. *Aquatic Botany*: 84(4), 347-353. doi:http://dx.doi.org/10.1016/j.aquabot.2006.01.002