Ten Year Management Plan for Lagarosiphon at Lake Dunstan: 2016 to 2025

Prepared for Land Information New Zealand and the Lake Dunstan Aquatic Weed Management Group

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The Lake Dunstan Aquatic Weed Management Group support the intentions of this document in guiding the management of lagarosiphon at Lake Dunstan.

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Executive summary

This Management Plan seeks to provide a shared view of lagarosiphon management in Lake Dunstan over the next ten years (2016 to 2025). A multi-agency stakeholder group, the Lake Dunstan Weed Management Group, has been established to provide strategic oversight of the programme to support implementation of the 10 Year Management Plan.

A vision statement, interrelated goals, objectives and milestones (Figure 1) are presented to guide management. Information on the ecology and impacts of lagarosiphon, history of invasion at Lake Dunstan and likely impacts on lake values are provided to background management needs and limitations.

Currently Lake Dunstan is 'saturated' by lagarosiphon (all available weed habitat is occupied) and lagarosiphon is present upstream in both the rivers feeding the lake. This reality limits the aims of management to 'sustained control'. One important driver for weed management is the risk that lagarosiphon presence at this important hub for water-based recreation poses to the other uninvaded Otago waterways. The second impetus is to mitigate the impacts of lagarosiphon on amenity values of Lake Dunstan for boating and swimming. In contrast, it is acknowledged that a highly valued recreational fishery is supported by the lagarosiphon weed beds that have replaced/excluded native submerged vegetation.

To date a lagarosiphon control programme funded by LINZ and Contact Energy has targeted 15 sites, including 14 High Value Areas identified in the Pest Management Strategy for Otago. This includes high use amenity and access areas, but privately owned inlets, jetties and marinas are not included. This Management Plan suggests site prioritisation criteria that may be used to select new sites or to rank existing ones for management importance.

Appropriate control options for lagarosiphon in Lake Dunstan are reviewed against criteria including suitability for large weed beds, availability of control technology in New Zealand and feasibility (operational and budgetary). Suitable options are identified as aquatic herbicides (diquat and possibly endothall) and mechanical cutting (with or without harvesting).

Eleven milestones are presented to guide and measure progress in the management of lagarosiphon at Lake Dunstan. These milestones incorporate key control actions but also consider a wider range of initiatives including public advocacy. It is envisaged that an annual process will set weed control priorities.

A review of this Management Plan after five years (2020) will compare progress achieved against the key milestones and reassess the goals, objectives and milestones for the next five years.

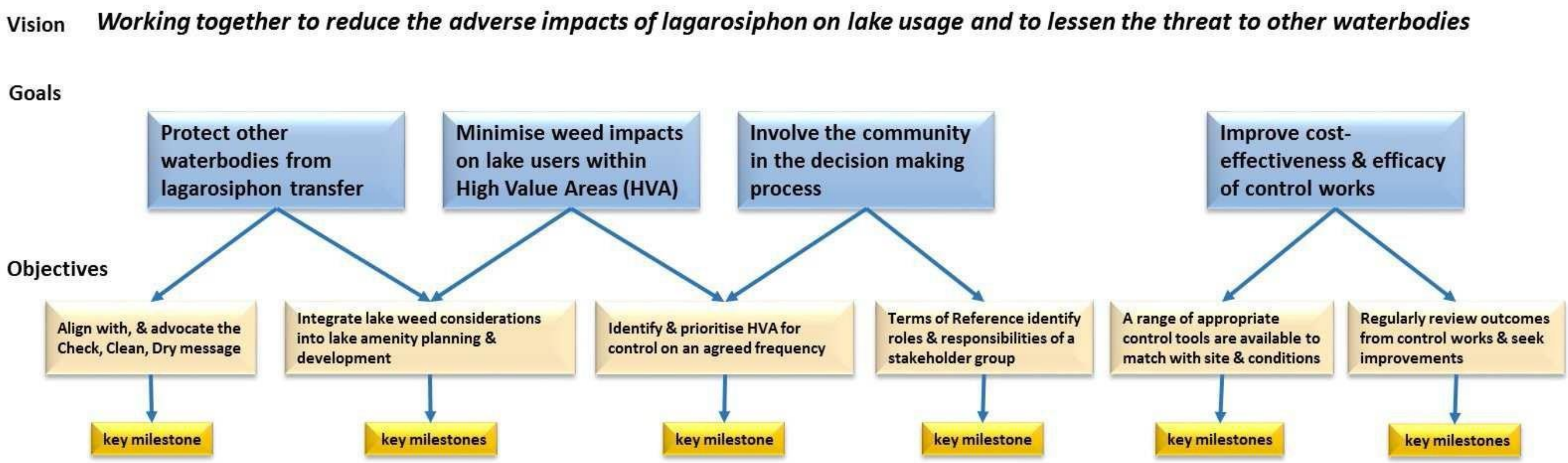

Figure 1: High level vision statement, goals and integrated objectives of the lagarosiphon management plan for the Lake Dunstan 2016 - 2025.

1 Introduction

Lake Dunstan (Te Wairere) is the most recently constructed large (26 km^2) man-made lake in New Zealand. Filled in 1993 following the Clyde Dam project, the lake and surrounds are still changing and maturing.

One of the planned benefits of the lake construction, in addition to hydro-electric generation, was for recreational usage. However, even before the construction began the presence of the aquatic weed lagarosiphon (*Lagarosiphon major*) in the upstream Clutha (Mata-au) catchment was a latent risk to the values of the proposed lake particularly for swimming, water skiing, boating and angling both from shore and boat. Today lagarosiphon has occupied all available habitat in Lake Dunstan and poses problems to recreational amenity in high use areas of the lake.

Aquatic plants fill an important role in the lake ecosystems and in the case of Lake Dunstan lagarosiphon is considered to make a significant contribution to lake fishery productivity and wildlife habitat values despite its nuisance status in high use areas.

Because of the continued upstream sources of this weed from Lake Wanaka and the extent of current development, feasible management of lagarosiphon is limited to control of nuisance growths and containment to protect other high value waterbodies in the area. An important aspect for ongoing lagarosiphon management will be agreement by agencies and lake users on the priority areas for lagarosiphon control, frequency of control and the outcomes sought from control.

This Management Plan seeks to provide a shared view of lagarosiphon management over the next 10 years (2016 to 2025). Related to this plan is the establishment of the Lake Dunstan Weed Management Group, with representatives from Land Information New Zealand (LINZ), Otago Regional Council, Contact Energy Limited, Central Otago District Council, Kāi Tahu, Otago Fish and Game Council, The Clutha Fisheries Trust, Cromwell and Districts Community Trust, and the Guardians of Lake Dunstan.

2 Ten Year Management Plan 2016 – 2025

2.1 Vision statement

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

Working together to reduce the adverse impacts of lagarosiphon on lake usage and to lessen the threat to other waterbodies.

2.2 Management Goals

Four high level goals are identified for 2016 to 2025 (Figure 1). These goals are strongly interrelated.

Goal 1: Protect other waterbodies from lagarosiphon transfer.

A range of high value waterbodies in the Otago and adjacent regions are vulnerable to lagarosiphon invasion from fragments sourced from Lake Dunstan on contaminated water craft and equipment. The Check, Clean, Dry programme initiated by the Ministry of Primary Industries (MPI) should be supported by advocacy and other initiatives. Such initiatives will also help address the threat posed by other invasive aquatic weeds, such as hornwort (*Ceratophyllum demersum*). Future planning and rationalisation of lakeside amenities should also consider habitat suitability for aquatic weed development and how to reduce risk of spread, while at the same time benefiting users of lake amenities.

Goal 2: Minimise weed impacts on lake users within High Value Areas (HVA).

Given the upstream sources of lagarosiphon, and the widespread status of the weed in Lake Dunstan, the only currently feasible objective for weed management is sustained control (see glossary terms). The areas for focussing sustained control in Lake Dunstan have been defined as High Value Areas (HVA). For control works to benefit the majority of lake users there needs to be a prioritisation of HVA for control works, based on the predominant use areas, the level of impact by local lagarosiphon development, and the outcomes that can be achieved by control. An agreed prioritisation process will help ensure the control works budget can be used to maximum effect.

Goal 3: Involve the community in the decision making process.

Local community and representative agencies have knowledge of the recreational use patterns and nature of impacts from lagarosiphon at Lake Dunstan. They also stand to gain the most from an effective lagarosiphon control programme. Embedding community views and aspirations into the management response will not only ensure relevant control targets, but also better engage with the public in terms of conveying risks of lagarosiphon spread to other valued waterways.

Goal 4: Improve cost-effectiveness & efficacy of control works.

Budgetary constraints mean that cost-effective control works which achieve the best outcome will see the greatest degree of control achieved across the prioritised sites. Important to this goal is that a full range of potential control methods are considered that are matched to the site conditions and outcomes sought. Control outcomes should be assessed, documented and communicated to the Lake Dunstan Aquatic Weed Management Group to inform expectations and aspirations. New and alternative control methods may have a place in the control programme once they have been validated from an effectiveness, environmental and economic viewpoint.

2.3 Management Objectives

To support the goals above, six objectives identify specific intentions of the management plan.

Objective 1: Align with, and advocate the Check, Clean, Dry message.

The Ministry for Primary Industries (MPI) co-ordinate a national Check, Clean, Dry campaign to raise public awareness on freshwater pests. Initiatives at Lake Dunstan should use this message and available resources to promote the threat of lagarosiphon transfer from Lake Dunstan to other pristine waterbodies, and address the threat posed to the lake by other freshwater pests.

Objective 2: Integrate lake weed considerations into lake amenity planning & development.

Unfortunately there is often overlap between the siting of lakeside amenities and the prime habitat for development of aquatic weeds (i.e., sheltered, low slope shores). There is scope for future amenity development to consider potential weed impacts and to avoid or negate this in the planning and development stage.

Objective 3: Identify and prioritise HVA for control on an agreed frequency.

A prioritisation process is needed to identify the sites for lagarosiphon control and to rank them so that control works can be applied where need is greatest. It should also be recognised that site priorities may change over time. Resulting priorities will be more defensible, resources can be apportioned accordingly and control works planned more effectively.

Objective 4: Terms of Reference identify roles and responsibilities of a stakeholder group.

A document is needed that formalises the roles and responsibilities of participating agencies in the Lake Dunstan Aquatic Weed Management Group and the expectations for their involvement in the management of lagarosiphon and processes/procedures towards this. In addition, it will be necessary to identify the lines of responsibility for communication with external agencies and media.

Objective 5: A range of appropriate control tools are available to match with site and conditions.

An 'integrated control' approach has many advantages for the management of lagarosiphon in Lake Dunstan. This recognises the best control outcome may require a combination of technologies to remove lagarosiphon. Some potential control techniques need to be screened for application to Lake Dunstan before they can be adopted.

Objective 6: Regularly review outcomes from control works and seek improvements.

Adaptive management is an essential component of every waterbody management plan. This can only be achieved by documenting and reviewing what works best for each area of focus and amending tactics accordingly.

3 Agencies: interests and responsibilities

The Lake Dunstan Weed Management Group has been established to agree an integrated approach to the management of lagarosiphon in Lake Dunstan. The group comprises representatives from community bodies, Iwi, local and central government agencies:

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 Dunstan and associated weed and pest control programmes. LINZ represents the Crown as owner of the lakebed pursuant to the Land Act 1948.

Central Otago District Council

Central Otago District Council's responsibility centers primarily on its obligations under the Resource Management Act and delegated functions and duties of Harbourmaster for Lake Dunstan.

Contact Energy Limited

Contact owns and operates two hydro-electric power stations at Clyde and Roxburgh as well as the Hawea Dam structure at Lake Hawea. Contact's Clutha operations meet approximately 10 per cent of New Zealand's electricity demand. Contact is the holder of an Operating Easement over much of the Clutha catchment, including Lake Dunstan.

Cromwell and Districts Community Trust

The Cromwell and Districts Community Trust ensures the wishes of its community members, through the Cromwell Community Plan, are heard and actioned. Advocating for weed control in Lake Dunstan is within these action points/priorities.

Guardians of Lake Dunstan

The Guardians (registered as the Lake Dunstan Charitable Trust Board) are a local community group of volunteers advocating for major improvements in and around Lake Dunstan. The Guardians seek to work closely with other agencies involved in lagarosiphon management, promote advances in control methods and see better weed management outcomes for the community.

Otago Fish and Game Council

Otago Fish and Game Council (OFGC) manages the sports fish and game bird resources and their habitats within the Otago Region in the interests of anglers and hunters under the Conservation Act 1987 and the Wildlife Act 1953. The Lake Dunstan trout fishery is considered to be nationally important in terms of the recreational fishing it supports. The lake is also a habitat for a variety of wildlife including game birds. Wildlife habitat values are particularly high in the Bendigo area at the head of the Clutha arm of the lake.

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.

The Clutha Fisheries Trust

The primary purpose of the Trust is defined as “To establish, maintain and enhance primarily the sports fisheries values and secondarily the conservation values of the waters of the Clutha catchment for the benefit of the people of New Zealand in recognition of the effects of the Clyde Dam development”.

Kāi Tahu

Kāi Tahu are tangata whenua within Otago and have a responsibility as kaitiaki of the environment. Their cultural, spiritual, historic, and traditional association to Te Wairere (Lake Dunstan) is acknowledged by the Crown[a].

[a] *Ngāi Tahu Claims Settlement Act 1998. Schedule 61. Statutory acknowledgement for Te Wairere (Lake Dunstan) http://www.legislation.govt.nz/act/public/1998/0097/28.0/DLM430894.html*

4 Background

Lagarosiphon ecology and management 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[1]. 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[2], and rarely fruits[3]. Lagarosiphon has been recognised as invasive in Ireland[4], the Netherlands[5] United Kingdom, France, Belgium, Switzerland, Italy, Reunion, as well as New Zealand[6].

Only female lagarosiphon plants are present in this country[1]. Despite being clonal and having very little genetic variation, lagarosiphon shows adaptation to a range of environments[7].

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[8]. 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*[9]. 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[8]. 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[8]. In a statistical modelling approach the known distribution of lagarosiphon in New Zealand lakes was best explained by road development and human population densities around infested lakes as measures of recreational access[10].

Lagarosiphon was first reported as a naturalised species in New Zealand in 1950. It was introduced by the aquarium and pond plant trade[11] 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[12]. Lagarosiphon is present in Lake Wanaka, 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).

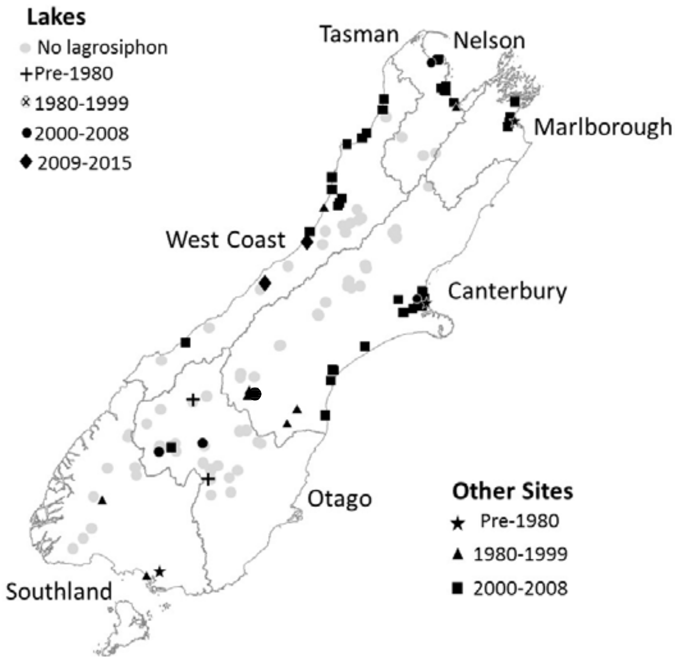

Figure 2: Distribution of lagarosiphon records in the South Island, but note some small sites have since been eradicated. Map modified from de Winton et al. (2009).

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[13 14]. For instance, nuisance surface reaching weed beds were limited to areas with a wind-wave fetch <4 km in Lake Taupo[14], 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[15] lists lagarosiphon as being managed for containment and amenity in specified 'Lagarosiphon High Value Areas' (HVA's) in Lake Dunstan and the Clutha River. Lagarosiphon has a 'Containment' status in the southern region of Lake Wanaka and elsewhere in Otago Region it is designated a 'Total Control Species'. The Operational Plan for the Pest Management Strategy for Otago that covers the period 2009 to 2019[16] 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[17], by shading native plants through the development of an extremely dense subsurface canopy and by having a physiological advantage over potential competitors[18]. Consequently, lagarosiphon displaces and excludes native vegetation leading to monospecific beds of low diversity[1 19].

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[13 20]. In Lake Wanaka the abundance of macroinvertebrates was higher per unit area within lagarosiphon beds than native vegetation[20], yet macroinvertebrate abundance was enhanced per unit macrophyte biomass where channels were cut through the lagarosiphon in Lake Dunstan[21]. This inconsistency may be related to lagarosiphon biomass, which was 12 fold greater in Lake Dunstan. It is thought that lagarosiphon may reduce fish access to macroinvertebrate food[20], whereas cut channels within large weed beds may enhance fish access and feeding[21].

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[13] and found to create progressively stressful conditions of high pH and low CO_2 content under experimental conditions[22]. 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[20]. This productivity may contribute to the observation that dense lagarosiphon beds accumulate deep deposits of flocculent organic mud[13].

History of lagarosiphon infestation of the Clutha River and Lake Dunstan

Lagarosiphon was first recorded within the Clutha Catchment at Lake Wanaka from 1972[12]. There followed a number of years where control works sought to limit the spread of lagarosiphon into the Clutha River. It was not until 1988 that lagarosiphon in the upper Clutha River was considered beyond a manageable level for containment or eradication.

The upstream presence of lagarosiphon was explored as a risk to the planned Clyde hydro-generation scheme and, in as early as 1977, large weed beds were predicted to develop in the Clutha Arm (Figure 3) of Lake Dunstan in particular[23]. The design phase considered removal of topsoil from areas to be inundated as a means to limit weed growth[24]. However, contouring to avoid creating weed habitat (i.e., removing terraces at 2-4 m depth) was deemed too expensive and, as tools for potential weed management existed, this weed risk was considered acceptable. Indeed, the environmental impact report at this time stated 'an aquatic plant management programme will be formulated in order to effectively minimise any potentially adverse effects and to obtain the maximum benefits for a multiple water use'[24].

Although Lake Dustan was filled by 1993, by 1996 development by lagarosiphon was still 'far from its full potential'[25]. Native submerged vegetation had established rapidly, probably due to greater sources in the Clutha River, but lagarosiphon subsequently invaded and replaced the native plants, which now only persist beyond the most favourable habitat and depth range of lagarosiphon.

Bannockburn Inlet and the Kawarau Arm took longer for lagarosiphon to invade[26] because of absence of fragment sources from the Kawarau River at this time and probably occurred with boat transfer of weed to this arm. Lagarosiphon can fulfil nutrient requirements from sediment sources and so would not have responded strongly to varying water nutrient levels, although Lake Dunstan, like other newly flooded reservoirs, did have temporarily higher water nutrient levels in the mid-1990s[27]. Based on annual monitoring from 1994, little potential for further spread by lagarosiphon was identified by 1998[26].

Lagarosiphon was first recorded in the upper Kawarau River in 2008[12], so now both arms that feed Lake Dunstan contribute source fragments of lagarosiphon and further reduce the feasibility of targeted shoreline removal of lagarosiphon.

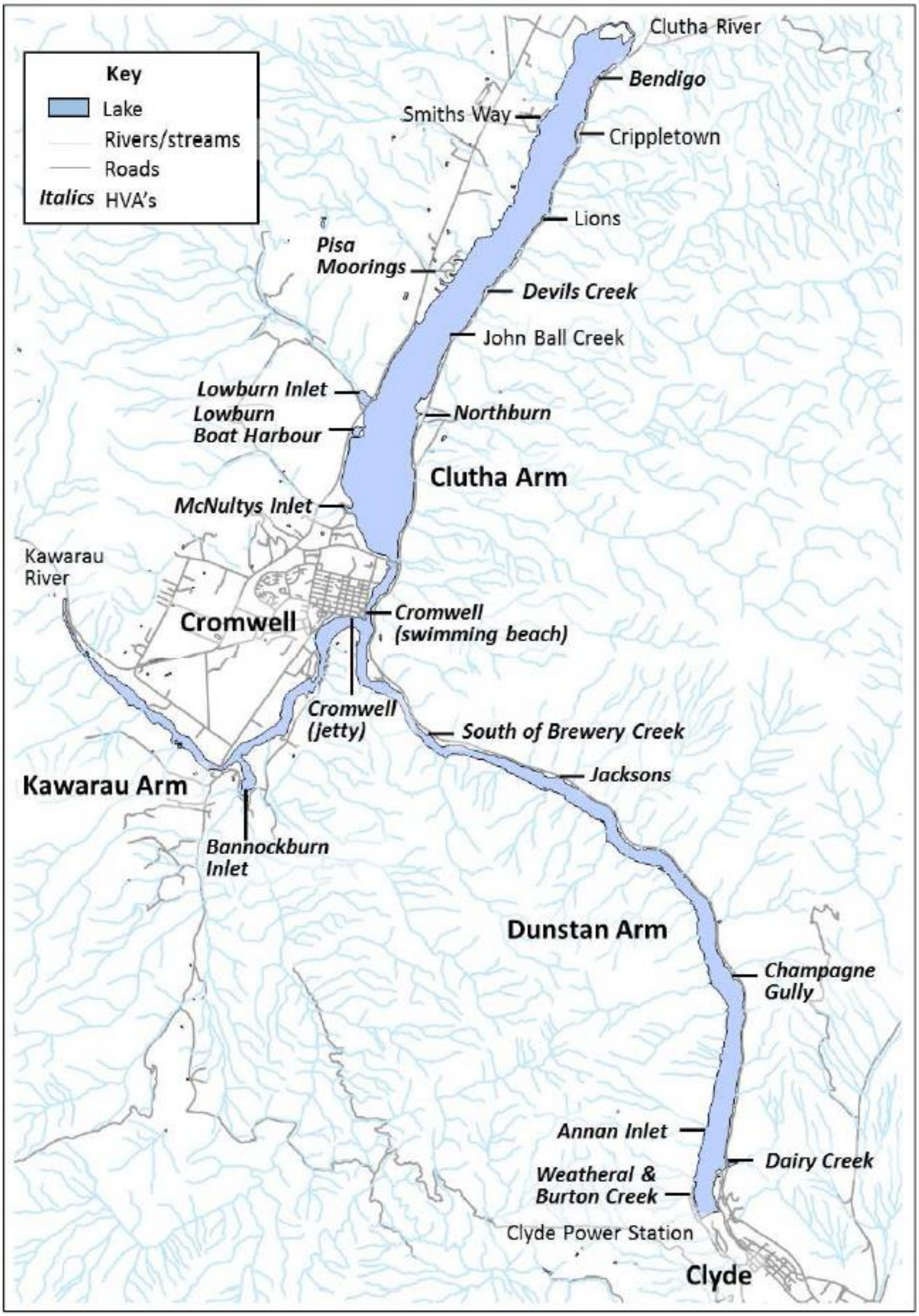

Figure 3: Map of the Lake Dunstan with amenity areas as noted in Clutha River/Mata-au Plan[41], with current (2016) HVA's[15] shown in italics.

Values at risk

The creation of Lake Dunstan planned to provide maximum recreation potentials via road access, boating facilities, parking areas, walkways and other amenities[24]. Additional shoreline excavation at some sites was aimed at creating attractive aquatic use areas. This was in part, compensation for the lost previous values of the area.

Residential and lifestyle properties flank various parts of the lake including around inlets (Pisa Moorings, Lowburn and Bannockburn Inlets), Northburn, and Cromwell Township (Figure 3). Local property values can be reduced by lake weed development. 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[28]. Nevertheless, actual impacts for New Zealand lakes cannot be stated without specific analysis of the value of properties related to public perception of acceptable levels of weed.

Lake Dunstan has significant infrastructure to support popular on-water activities involving boating and fishing. Ten formal boat ramps provide good access to the lake[29]. The Lake Dunstan Boat Club clubs and Cromwell College Aquatic Centre are located at McNulty Inlet and the Dunstan Arm Rowing Club Incorporated is based at the end of the Dunstan Arm, with headquarters at Weatheral Creek. In addition, picnic and foot access to the lake are provided at 14 sites[29]. Popular swimming areas include part of Bannockburn Inlet, Lowburn Boat Harbour, Lowburn Inlet, Fernbrook, Northburn Inlet, from the township at Cromwell Jetty (old Cromwell) and Cromwell swimming beach.

Large beds of canopy-forming weeds are associated with depressed quantity and quality of boating, swimming and nearshore recreation[30]. Entanglement and drownings have been linked to invasive weed beds[31], while dense mats of weed provide good habitat for the snail hosts of parasites that cause ‘swimmer’s (duck) itch’[30], which has been recorded upstream at Lake Wanaka.

Economic estimates of weed impacts on recreation are rare. In one study of a submerged weed, hydrilla, on a Florida lake (108 km^2), recreational values at risk from hydrilla were estimated at US$857,000 annually[32]. 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[32].

In the national angler survey of 2007/8, Lake Dunstan had an estimated 26,140 angler days, representing 11.6% of angler days in the Otago Region and 19.6% of days spent on lakes in the region. Lake Dunstan is recognised as a ‘weed based fishery’ requiring fishing techniques and equipment suited to this environment[29]. Although lagarosiphon impacts on boating and interferes with fishing activities, especially shore-based, the general consensus is that the combination of weed beds and adjacent navigable areas provide for excellent fishing from boats.

Research in Lake Dunstan showed native fish (common bully) abundance was associated with the presence of lagarosiphon weed beds at small spatial scales, and that macroinvertebrate composition in the weed beds overlapped with the prey items of the fish[33]. This agrees with other findings that lagarosiphon in the wider Clutha River and lakes system provides similar food source and habitat benefits to fisheries as native submerged plants[20, 34] that would otherwise be present.

Hydro-electric generation is the major utility value for the lake, although there are also water takes for irrigation (Cromwell terrace)[35], an alternative water supply for the township of Clyde[36] and discharges to the lake (e.g., the Cromwell Waste Water Treatment Plant[27]). The Clyde Power Station contributed 4.3% of electricity generation capacity in 2014[37]. Fortunately the configuration of the lake, with the long steep-sided Dunstan Arm, means little habitat for lagarosiphon is near the power station. This together with the station design means Clyde Dam does not experience large impacts from lagarosiphon. Irrigation takes are primarily from the Kawarau Arm[35] with little scope for blockages by lagarosiphon with the potential exception of the Bannockburn Inlet.

Although lagarosiphon is the focus of this management plan and the most immediate threat to the values of Lake Dunstan, a more significant threat is posed by the aquatic weed hornwort (*Ceratophyllum demersum*), a major weed of hydro-generation lakes in the North Island. Hornwort is not listed on the Regional Pest Management Strategy[15], presumably because it is designated as a 'National Interest Pest' for the South Island with the discovery of any incursions falling under the management of the Ministry for Primary Industries (MPI). Nevertheless, it is important to proactively reduce the threat of hornwort establishing in Lake Dunstan and to undertake surveillance for this weed at high risk sites (e.g., high amenity usage).

Lake Dunstan represents a source of lagarosiphon that is a substantial risk to iconic Lake Wakatipu, as well as other un-infested lakes in Otago and adjacent regions. Several lagarosiphon incursions have been removed from Lake Wakatipu, with the risk of weed transfer from Lake Dunstan second only to the upper Kawarau River, and probably a greater risk than transfer from Lake Wanaka.

5 Current status

In terms of potential habitat for lagarosiphon, Lake Dunstan presents only moderately suitable shoreline shape, littoral gradient and exposure to wave action[38]. Much of the lake shorelines are steep, with a long wind and wave fetch down the arms. However, there are protected sites and inlets that allow weed beds to develop, and these frequently overlap with areas developed for lake access and use. Submerged river terraces within the suitable depth range of lagarosiphon support weed beds if they are sheltered (e.g., adjacent to Pegasus Crescent, Pisa Moorings). Water level fluctuation is minor (<1 m) and would not impact on the depth range of lagarosiphon[38].

Lagarosiphon occupies all favourable habitat available for the weed in Lake Dunstan (i.e., habitat saturated). The greatest areas of weed bed are at the submerged river flats and delta at the head of the Clutha Arm (Figure 4), where water flow, depth and clarity are ideal for submerged plant growth. Lagarosiphon grows mostly between 0.5 to 5 m depth in the Clutha Arm with near surface-reaching beds extending from depths up to 4.5 m. In the Kawarau Arm the extent of the water depth suitable for lagarosiphon is limited by the more turbid water which reduces light for plant growth. In the Dunstan Arm the steep sides of this reach limit the areas for weed development.

Lagarosiphon tolerates a wide range of substrates but grows best on fine sediments. It is also considered a 'transformer' species or 'ecological engineer' that can modify wave motion and promote sediment build-up that then improves suitability for lagarosiphon growth at the site.

Based on suitable depth range and levels of exposure at shorelines, it was estimated that about 500 ha of lake bed would support lagarosiphon[39] and 139 ha of this was thought likely to impact on recreational use[40].

Figure 4: **View towards the Pisa Range at Bendigo showing lagarosiphon development at the Clutha Delta.**

6 Scenario of no management

Because available habitat is already saturated by lagarosiphon, we would not expect any future expansions in the distribution of weeds beds. However, the density and height of lagarosiphon would be expected to increase under a scenario of no management, with possible 'self-enhancement' of sites for growth by lagarosiphon as fine sediments are built up and wave action is buffered by the weed beds. We note that no control of lagarosiphon at Lake Dunstan is unlikely to be acceptable under the Regional Pest Management Strategy for Otago Region, which has a strong focus for preventing lagarosiphon spread.

Of relevance to lagarosiphon in the Kawarau Arm is that this lake reach will change into a river environment down to the meeting with the Clutha Arm at Cromwell[27]. Although the considerable shallowing to an expected average depth of 5m is expected[27], the increased velocities and low water clarity will continue to limit lagarosiphon development. However, the future for boat launching and jetty facilities at Cromwell (jetty) HVA is not clear. Silting at jetties and boat access way/shallow water by boat ramps at this site is already noted[41].

7 Control options

Methodologies for lagarosiphon control (Appendix A) differ in their suitability depending on biomass and extent of lagarosiphon and site characteristics. An initial assessment of control methodologies suitable for the large weed beds found in Lake Dunstan involved screening methodologies against three key criteria (Appendix B). This process identified feasible control methodologies as herbicide (diquat or endothall) and mechanical cutting (including potential harvesting).

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[42 43]. 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 one year from treatment.

Diquat is a widely used herbicide[44] that is relatively fast acting[45]. The active ingredient is diquat dibromide, with a concentration of 1 mg per litre (i.e., a 1:1,000,000 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[42]. 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 can be reduced in turbid water[46] or where plants are covered in organic matter or deposits of silt, which can rapidly bind and deactivate 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[42]. 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[47].

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[48]. Further research to evaluate endothall as a potential control tool in a large lake such as Lake Dunstan is required before this option could be recommended.

Mechanical harvesting generally refers to the cutting and disposal of lake weed. Although here we consider commercially produced cutting/harvesting machines, there is potential for other engineering solutions that each need to be considered on their merit and achievable outcomes.

Typically, cutters/harvesters comprise a boat-mounted sickle bar that cuts the weed below the water surface. For harvesters the weed is entrained onto a conveyor belt as the machine moves forward.

The collected lake weed may then be transported to shore directly for "out-of-lake" disposal. Offloading sites usually must be paved or concreted to ensure heavy machinery and vehicles involved in weed disposal do not get stuck in boggy ground[49]. Most machines cut or harvest weed from water depths down to c. 2 m below the water surface. However some recent models are able to extract weed (at limited volumes) from water depths up to 5 m (e.g., Freshwater Environmental Management Pty Ltd FEM 625-8). The 70 ft "Kelpin" harvester with a 5 m cutting swath and 3 m depth range can reportedly harvest up to 4047 m^2 of surface-matted hydrilla (*Hydrilla verticillata*) per hour[50].

The operational attributes of the Lakeweed harvester that currently harvests hornwort in Lake Rotoehu (Bay of Plenty) are as follows (H Emeny pers comm., Lakeweed Harvesters & Contractors, August 2015):

- moves at a speed of 4 km/h with a full load and at a speed of c. 3 km/h when cutting
- it can accommodate 10 m^3 of wet weed which takes c. 6 min to load (if the weed is dense)
- it cuts in a 2 m wide swath to a maximum depth of 1.8 m (ideal maximum cutting depth is 1.2 m)
- it can clear a ca 5 ha area of dense weed in approximately 120 h with a 50 m distance to offload onshore; this is equivalent to a harvesting rate of 400 m^2/h.

To reduce offloading time, which is a substantial part of harvesting operations, cut weed may be shredded/mulched using a boat-mounted pulveriser and discharged back into the water thereby eliminating the need for shore disposal[51 52]. In-lake disposal of hydrilla was found to reduce machine down time by 50%[51]. Alternatively, in a 'habitat saturated' weed situation (like Lake Dunstan) the weed may be directly released without shredding to deposit in unfavourable depths or shorelines. However, should weed deposit onshore in nuisance amounts there may be the need to remove it with an excavator.

Shredders/mulchers are not readily available on the commercial market. The few units currently in operation in New Zealand have been constructed in-house (e.g., "Lois" by Mighty River Power). The in-lake shredding unit operated by Mighty River Power for management of drifting weed (not littoral weed beds) can process weed at the following estimated rates which vary depending on weed density: 603 m^3/h for very dense weed, 186 m^3/h for dense weed, 93 m^3/h for medium density weed and 46 m^3/h for low density weed[53 54].

Mechanical cutting/harvesting will not remove all weed biomass, and weed beds can re-establish relatively quickly from remnant lagarosiphon stems and root crowns that are not removed. Assuming modest relative growth rates for lagarosiphon[55] of 0.02 to 0.03 length increase day^{-1}, lagarosiphon stems cut to 0.1 m height could grow to 2 m height in 100 days, or 50 days for the same growth using a higher reported growth rate[56] for lagarosiphon of up to 0.063 day^{-1}.

Mechanical harvesting is often perceived to be environmentally neutral[49], but use of commercial harvesters is known to entrap and kill fish and invertebrates that live in the harvested weed[57 58 59]. Disturbance of bottom sediments during harvesting operations results in localised increases in water turbidity and dissolved nutrient concentrations[60].

Integrated control refers to a combination of methods applied to achieve a better outcome than one 'blanket' technique. The need for integrated control may be due to site characteristics that reduce the effectiveness of one approach, such as consistently dirty plants that reduce the efficacy of diquat herbicide. A mechanical cutting may also lead to fresh plant growth that is then more susceptible to diquat action. These tactics need to be tested and refined for Lake Dunstan, and other control techniques need to be screened for acceptable application within the lagarosiphon control programme.

8 Management strategies

A 5-year (2001-2006) management plan for lagarosiphon on lake and river beds in Otago[61] stated the intentions of managing the existing amenity values of Lake Dunstan, as well as preventing the establishment of lagarosiphon in non-infested South Island lakes. In this present management plan we consider a wider range of goals and objectives (Section 2.2 and 2.3).

This current management plan also aligns with the Regional Pest Management Strategy 2009 (RPMS) for the Otago Region[15]. It states the aim at Lake Dunstan as containment and amenity. An important consideration here is the risk that lagarosiphon at Lake Dunstan poses as a source for contamination of Lake Wakatipu and other Otago waterbodies. The RPMS outlines 14 High Value Areas (HVA) identified by consultation as important for amenity reasons, including most of the boat ramps.

Community plans indicate the aspirations of the community, although they do not have any statutory obligation on organisations[41]. The Cromwell Community Plan[62] recognises the importance of Lake Dunstan for water sports and activities. One recommendation for action was for the Community Trust to advocate for weed control in Lake Dunstan[62], but also that the community want recreational areas developed that are outside the high use areas identified 'by LINZ'[62]. The control of aquatic weeds features strongly in the Pisa District Community Plan[63], because, as a lakeside settlement, access and use of Lake Dunstan is a high priority. Interest in extending lake facilities (i.e., floating pontoon, ski lane) were also identified.

Currently the LINZ/Contact Energy funded lagarosiphon management programme targets an area of approximately 70 ha across the HVA's. Privately owned inlets, jetties and marinas are not included within the LINZ/Contact Energy programme, but may benefit from consideration within this plan where relevant.

9 Key milestones

Milestones are numbered 1 to 6 in relation to the objectives identified in Section 2.3. These milestones provide the means for checking progress and that the programme is on track. See Appendix E for overview of milestone activities by year.

Objective 1: Align with & advocate the Check, Clean, Dry campaign.

Milestone 1A *A refreshed and ongoing campaign informs the public of the risks posed by freshwater pests and actions they can take to prevent weed spread (2016 to 2025).*

The Check, Clean, Dry programme initiated by MPI provides an overarching message and associated resources (e.g., cleaning protocols) for freshwater biosecurity. Initiatives at Lake Dunstan should use the Check, Clean, Dry message on signage at boat ramps, in radio campaigns and print resources, as well as in advocacy from trained personnel at targeted venues during periods of high recreational use, and at water sport events. Other initiatives could include wash-down facilities and/or weed cordons (netted enclosures at boat ramps) if these were agreed by the Lake Dunstan Aquatic Weed Management Group.

Objective 2: Integrate weed considerations into lake amenity planning & development.

Milestone 2A *Future development and replacement of lakeside amenities includes consideration of lagarosiphon impacts and risks (2016 to 2025).*

Development of lake-side amenities should consider local weed development and contamination risks at the design stage with a view to minimising the impact by lagarosiphon and risk of transfer. This would include considering shoreline gradient and exposure when locating reserves and their amenities, especially boat ramps, ski lane access points, jetties and pontoons.

Milestone 2B *Rationalise boat launching sites to high use amenities and earmark these sites for weed hygiene to prevent lagarosiphon spread by 2018.*

Lake Dunstan has a large number of lake access points where trailer boats can be launched, including formal concrete ramps and rough tracks. An increased level of weed hygiene could be applied at a smaller number of launch sites. Rationalisation of less important access points for trailer boats might be undertaken following a consultative approach involving the community, Contact Energy, and LINZ as lake shore asset owner. Some secondary boat launch sites could be designated for non-motorised craft (e.g., kayaks and small dinghies) which present a lower weed spread risk. It is recognised that utility access to the lake shore is required by Contact Energy at some sites.

Objective 3: Identify & prioritise HVA for control on agreed frequency.

Milestone 3A *Agree on a process to identify and prioritise High Value Areas as a focus for control works, and the frequency at which these should be reassessed by 2017.*

Changing local population distribution, development of additional settlements and changing lake conditions (i.e., infilling) may drive changes in the key lakeside areas used for recreation. An agreed process for selecting and ranking the High Value Areas (HAV's) for recreational usage is needed which is transparent and defensible. Reassessment should be at an agreed frequency reflecting the rate of likely change. Documentation of the HVA is made via the Regional Pest Management Strategy (RPMS) for the Otago Region. A role for the Lake Dunstan Aquatic Weed Management Group should be the submission of an agreed list of HVAs for incorporation into future iterations of the RPMS (as

Regional Pest Management Plans). Ranking of the HVA for control priority should include the current investment in amenities at sites, their popularity, level of potential interference from lagarosiphon at each site and what control outcome may be achieved.

Milestone 3B *Agree on a process to identify annual weed control priorities by 2017.*

Closely linked to Milestone 3A is the agreed setting of a process for annual control priorities. This process should also be informed by previous weed control outcomes (see Milestone 6A) and any gains over time in reducing weed issues. It also needs to consider trialling of new control methodologies or tactics within annual priorities (Milestone 5A).

Milestone 3C *Weed bed areas that are identified for high angler or wildlife value are designated for no control by 2017.*

As well as identifying HVA's, it would be useful to reserve those areas where weed beds are perceived to add value for angling so that there is further visibility about the focus for control works.

Objective 4: An MOU identifies roles & responsibilities of a stakeholder group.

Milestone 4A *The basis for stakeholder engagement and input is clarified and agreed by 2017.*

The membership and nature of engagement for a stakeholder group, meeting as the Lake Dunstan Aquatic Weed Management Group, is documented and agreed in an MOU which includes frequency and timing of meetings, information to be provided to the group, and an agreed communications strategy that includes media communications made about the programme on behalf of the group. The MOU should also identify the level of operational and budgetary flexibility within the programme.

Objective 5: A range of appropriate control tools are available to match with site & conditions

Milestone 5A *New control methodologies are assessed for control of lagarosiphon and adopted if appropriate by 2017.*

Control methods additional to the ones currently used in Lake Dunstan may provide a solution for sites that have proved difficult to control to date, or as interim relief from weeds in the event of unforeseen issues (e.g., low lake levels at a time of high weed recovery). Mechanical control technologies currently under investigation include boat-based cutting and raking by a shore based, long-reach excavator. New methodologies should be carefully assessed from an efficacy, environmental and economic viewpoint, and agreed by the Lake Dunstan Aquatic Weed Management Group before adoption.

Milestone 5B *New technologies that become operational in New Zealand for lagarosiphon control are screened and adopted as appropriate by 2025.*

Additional herbicides that are in use in the US that could have application here if they prove effective against target species under New Zealand conditions. Future control options should be assessed for potential application to Lake Dunstan as they become operational.

Objective 6: Regularly review outcomes from control works & seek improvements.

Milestone 6A *Control outcomes are assessed and communicated to the stakeholder group for feedback on an annual basis (2016 to 2025).*

The degree that stakeholder and community aspirations are met by lagarosiphon control outcomes is important to recognise. Further dialogue on control outcomes will help refine community priorities and expectations.

Milestone 6B *Opportunities for improved control outcomes are identified annually (2016 to 2025).*

Based on recognised weed control options, any opportunity for further refinement to enhance control outcomes will be identified and assessed. This may require access to expert advice to help assess appropriateness.

10 Site Prioritisation Model

The selection of important amenity sites where control works should be focussed, and the allocation of budget across sites would benefit from a transparent and agreed process (Milestones 3A and 3B). An example prioritisation of the current (2016) HVA's for lagarosiphon control shows how sites could be ranked according to:

1. their level of amenity development (Appendix C), ranked 1 (highest) to 5 (lowest)
2. likely usage based on distance from population centres, ranked 1 to 3
3. and level of potential interference from lagarosiphon, ranked 1 to 3, based on NIWA's 2015 inspection.

The results of this example ranking is given in Appendix D. This process could form the basis for an annual prioritisation of sites by the Lake Dunstan Aquatic Weed Management Group, together with additional information on usage patterns. Sites may also be excluded for selection/prioritisation due to values associated with lagarosiphon weeds beds (i.e., angling or wildfowl value), or infeasibility of control (i.e., extensive areas).

An annual operational plan should be developed (Section 12) that considers site priorities, the available budget, cost of control at each site, the appropriate control methodology, and the level and duration of control that may be achieved ('bang for buck').

11 Record keeping

LINZ provide an annual record of the control works[64] which documents the location, method and area treated at each HVA. It will also be important to keep a record of outcomes from control works, including degree and duration of control, where additional unplanned treatments for weed relief have been necessary, as well as any public complaints, to build up a picture of where different site tactics or control methods may be required. Reporting these findings to the Lake Dunstan Aquatic Weed Management Group on an annual basis will ensure a common view of progress and issues and a foundation for planning the subsequent control.

12 Reviews and annual process

Setting the annual control priorities can be viewed as a process involving assessment of control outcomes, budget setting and allocation across agreed site priorities, leading to development of an annual operational plan (Figure 5).

Operations should identify the most cost-effective method at each site to achieve site specific outcomes that may include boat ramp hygiene, access for swimmers, access to other amenities (e.g., jetties, entrances to inlets) as well as general control for shoreline or ski lane access.

Once the budget priorities are agreed, LINZ biosecurity service partner, Boffa Miskell, engages experienced contractors that meet industry requirements. One of the initial tasks is to inspect the sites for weed and site conditions that may determine the timing of control or control methods used.

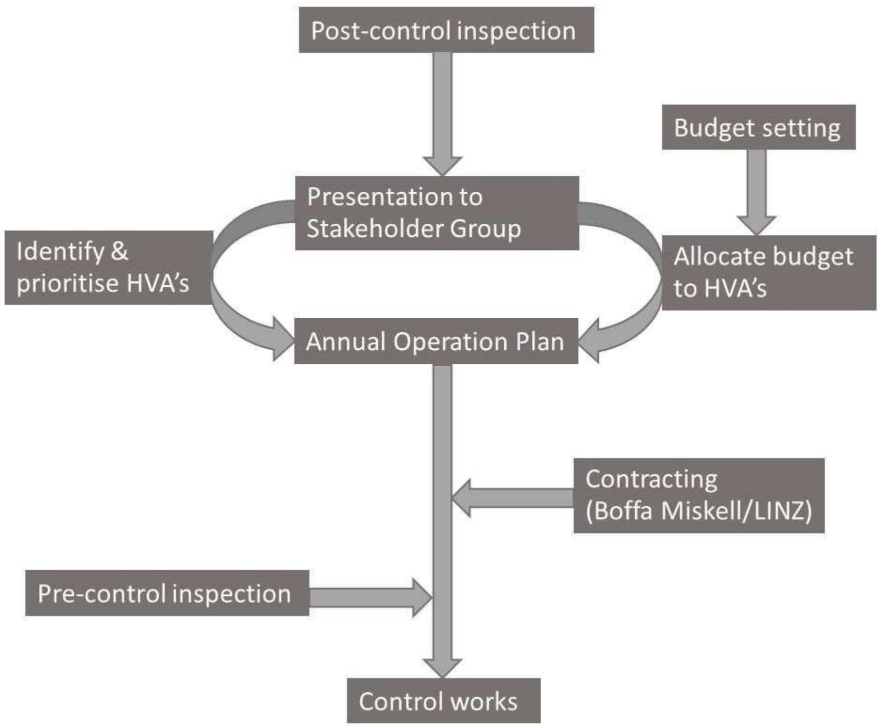

Figure 5: Annual process for planning the control works for Lake Dunstan.

A review of this Ten Year Management Plan after five years (2020) will compare progress achieved against the key milestones (Section 9) and reassess the goals, objectives and milestones for the next five years.

13 Risks

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

Funding loss

Currently the funding base for lagarosiphon control is from central government administered by LINZ, and from Contact Energy. There are no contributions from local rate-base sources, yet it could be argued that the local economy has the most to lose from lagarosiphon expansion. Reliance on a small sector or source of funding has the associated risk of re-allocation as agency priorities change (e.g., a new emerging biosecurity threat on crown land). We recognise that a broader funding base would provide better security for an ongoing lagarosiphon management programme.

Unrealistic public expectations

The nature of lagarosiphon and the situation at Lake Dunstan means that there are limitations to the extent of control that can be achieved on a spatial and temporal basis due both to feasibility and budgetary constraints. Providing the public with information on lagarosiphon and the aims and achievements of the management programme will be important to inform their expectations. It is also vital to have the community represented in decisions on lagarosiphon management.

Public opposition to control tools

Opposition from even small sectors of the community regarding use of some control tools (particularly herbicides) could potentially restrict the outcomes that can be achieved and result in adverse publicity for the management programme. Again, informing and engaging with the public, and communicating progress on lagarosiphon control works, is likely to moderate community support for extreme views.

Lake conditions constrain works

Lake, plant and weather conditions have the potential to impact on the feasibility and effectiveness of control methods. Amongst possible risks are local eutrophication (nutrient enrichment) with fouling on target plants reducing their susceptibility to diquat herbicide. Reduced hydrological flushing may occur with sedimentation at the heads of the Kawarau (e.g., Bannockburn) and Clutha Arms that also impacts on the effectiveness of this control method.

Contingency to accommodate such events should include transfer of budget from one year to the next. Equally it is important to retain flexibility in the programme to capitalise on good lake and weather conditions.

14 Acknowledgements

This management plan benefited from discussions with members of the Lake Dunstan Aquatic Weed Management Group, particularly David Mole (LINZ), Daniel Druce (Contact Energy Limited), Cliff Halford (Otago Fish and Game Council) and Andrew Burton (Guardians of Lake Dunstan). We appreciate the technical input of Marcus Girvan (Boffa Miskell) and weed control contractors.

15 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.
Harvesting	Removal of weed biomass from a lake after cutting.
Sustained control	To provide for ongoing control of the pest to reduce its impacts and its spread to other properties.

Appendix A 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	Only effective given small isolated plants.	High cost as labour intensive.	Immediate removal, no adverse effects.	Not feasible for weed habitat saturated situations.
Suction dredge	Only effective if no large contributory weed biomass areas nearby. Applicable to medium size patches/narrow beds.	High cost as labour intensive.	Immediate removal, but follow-up required, selective therefore few adverse effects.	Debris, rocky or hard packed substrates reduce effective removal & increase cost.
Mechanical cutter/harvester* *NB only commercially available harvesters	Can remove c. 80% of biomass if depth ≤ 2m & gradient suitable.	Machinery outlay is the major cost (c. $200k), $2,000-4,000 per hectare plus disposal costs.	Large areas can be controlled relatively quickly for amenity benefit.	Limited to cut of ≤2 m depth, possible obstructions for cutting (wood/rocks), rapid regrowth, non-selective, large release of fragments, machinery difficult to decontaminate therefore usually dedicated to a waterbody.
Harvester with mulcher	Dependant on control above being feasible, but significantly decrease treatment time and cost.	Lower cost than operating cost above by c. 40%.	Efficiencies gained.	May not be viewed as environmentally optimal disposal.
Rototiller	Can provide >6 months control over 1.5 to 4 m depth under suitable depth and sediment conditions[65 66].	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.

Method	Effectiveness	Relative cost	Advantages	Disadvantages
Diquat herbicide	Capable of removing >90% of biomass, control can last for one 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.	May be deactivated in turbid water, lake currents may remove or dilute herbicide, woody stems & root crowns highly resistant.
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[4.]			Not registered for aquatic use in New Zealand.
Grass carp	Not considered feasible for Lake Dunstan due to need for containment. Need stocking at sufficient density for sufficient time to remove target weed.	Very high cost (containment structure, approvals process).	Can eradicate lagarosiphon if all requirements in place (number of fish for long enough).	Unlikely to be contained in the lake, browsing at low temperatures <16°C may limit effectiveness, but may remove all submerged plants.
Classical biocontrol (host-specific insect)	Suppression of high biomass possible, will not achieve site eradication, may not achieve reduction at desired locations (i.e., cannot target specific sites/HVAs).	Development & testing costs high (national funding level) but release costs likely to be low	Potentially self-sustaining control agent populations achieved.	Not yet available in NZ, uncertainty over effectiveness, little success in USA.
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, uncertainty over effectiveness.

Method	Effectiveness	Relative cost	Advantages	Disadvantages
Water drawdown 4 to 5 m for c. 2 weeks.	Desiccation or freezing can reduce biomass temporarily.	Loss of hydro-generation, loss of recreational use.	Relatively easy if water level control structure allows and necessary consents for drawdown in place.	Huge impacts on recreational usage, Large adverse environmental effects likely (erosion, loss of fish habitat).
Bottom lining (new biodegradable materials).	Amenity control in limited areas, medium-term control (up to a few years), control in 4-5 months[67] [68].	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, feasible for limited areas, requires reduction of weed biomass first, sedimentation allows re-colonisation of area, lining can be dislodged by wave/currents.

Appendix B Selection of control methodologies against criteria

Table 2: Assessment of potential control methodologies for amenity control use in Lake Dunstan against key criteria. Methods in bold meet all criteria.

Method	Technology is available in New Zealand	Suitable for targeting large weed beds	Feasible given budgetary limitations of the programme
Hand removal	yes	no	no
Suction dredge	yes	no	?
Bottom lining	Yes	no	?
Diquat	**yes**	**yes**	**yes**
Endothall	**yes**	**yes**	**yes**
Mechanical cutter/harvester	**yes**	**yes**	**yes**
Rototiller	yes	no	no
Dichlobenil	no	yes	no (registration required)
Grass carp	yes	yes	no
Classical biocontrol	no	no	? yes
Mycoherbicide	no	?	?
Water drawdown	yes	?no	no

Appendix C Amenity development at HVA's

List of amenities[41] and example rankings (Section 10) from 1 (high amenity development) to 5 (lowest amenity development) for each of the current (2016) HVA's.

HVA	Amenities	Rank
Bendigo	Boat ramp, rest area, toilet block	2
Pisa Moorings	Boat ramp, rest area, private jetties	3
Devils Creek	Rest area	4
Lowburn Inlet	Rest area, swimming	3
Lowburn Boat Harbour	Boat ramp, (ski lane nearby), rest area, toilet block, floating jetty, swimming	1
Northburn	Boat ramp, rest area, ski lane	2
McNultys	Boat ramp, rest area, ski lane, toilet block, floating jetty	1
Cromwell (swimming beach)	Swimming pontoon, jetty, (ski lane nearby)	3
Cromwell (jetty)	Boat ramp, rest area, toilet block, floating jetty	1
Bannockburn Inlet	Boat ramp, rest area, toilet block, swimming pontoon	1
South of Brewery Creek		5
Jacksons	Rest area	4
Champagne Gully	Boat ramp, rest area, toilet block, ski lane	1
Annan Inlet		5
Dairy Creek	Boat ramp, rest area, toilet block, floating jetty, swimming	1
Weatheral & Burton Creek	Boat ramp, rest area, swimming pontoon, floating jetty	1

Appendix D Proposed site ranking

Example results of the priority ranking process (Section 10) with lower total rank score indicating higher priority.

HVA	Amenity Rank	Distance from population centres	Potential interference	Total rank score
Cromwell (jetty)	1	1	1	3
McNultys	1	1	2	4
Bannockburn Inlet	1	2	1	4
Weatheral & Burton Creek	1	1	2	4
Lowburn Boat Harbour	1	2	2	5
Northburn	2	2	1	5
Cromwell (swimming beach)	3	1	1	5
Bendigo	2	3	1	6
Pisa Moorings	3	2	1	6
Champagne Gully	1	3	2	6
Dairy Creek	1	2	3	6
Lowburn Inlet	3	2	2	7
Jacksons	4	3	1	8
Devils Creek	4	3	3	10
South of Brewery Creek	5	3	3	11
Annan Inlet	5	3	3	11

Appendix E Overview of milestone activities by year

Timing of milestone activities across 2016 to 2025, showing if they are ongoing (→) or date specific (*).

Milestones	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1A. Freshwater pest campaign	→	→	→	→	→	→	→	→	→	→
2A. Planned lakeside amenities to reduce impact	→	→	→	→	→	→	→	→	→	→
2B. Rationalise boat launching sites			*							
3A. ID & prioritise High Value Areas		*								
3B. ID priorities for annual weed control		→	→	→	→	→	→	→	→	→
3C. Designate no control areas		*								
4A. Develop stakeholder Terms of Reference		*								
5A. Assess new control methodologies		*								
5B. Adopt new operational technologies	→	→	→	→	→	→	→	→	→	→
6A. Reporting & feedback on control outcomes	→	→	→	→	→	→	→	→	→	→
6B. ID opportunities for improved control outcomes	→	→	→	→	→	→	→	→	→	→

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

Prepared for Land Information New Zealand and Boffa Miskell

February 2016

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Contents

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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
Land Information New Zealand	David Mole	
Guardians of Lake Wanaka	Don Robertson (Chair)	
Otago Regional Council	Jeff Donaldson	
Queenstown Lakes District Council	Calum MacLeod	
Department of Conservation	Chris Sydney	

Executive summary

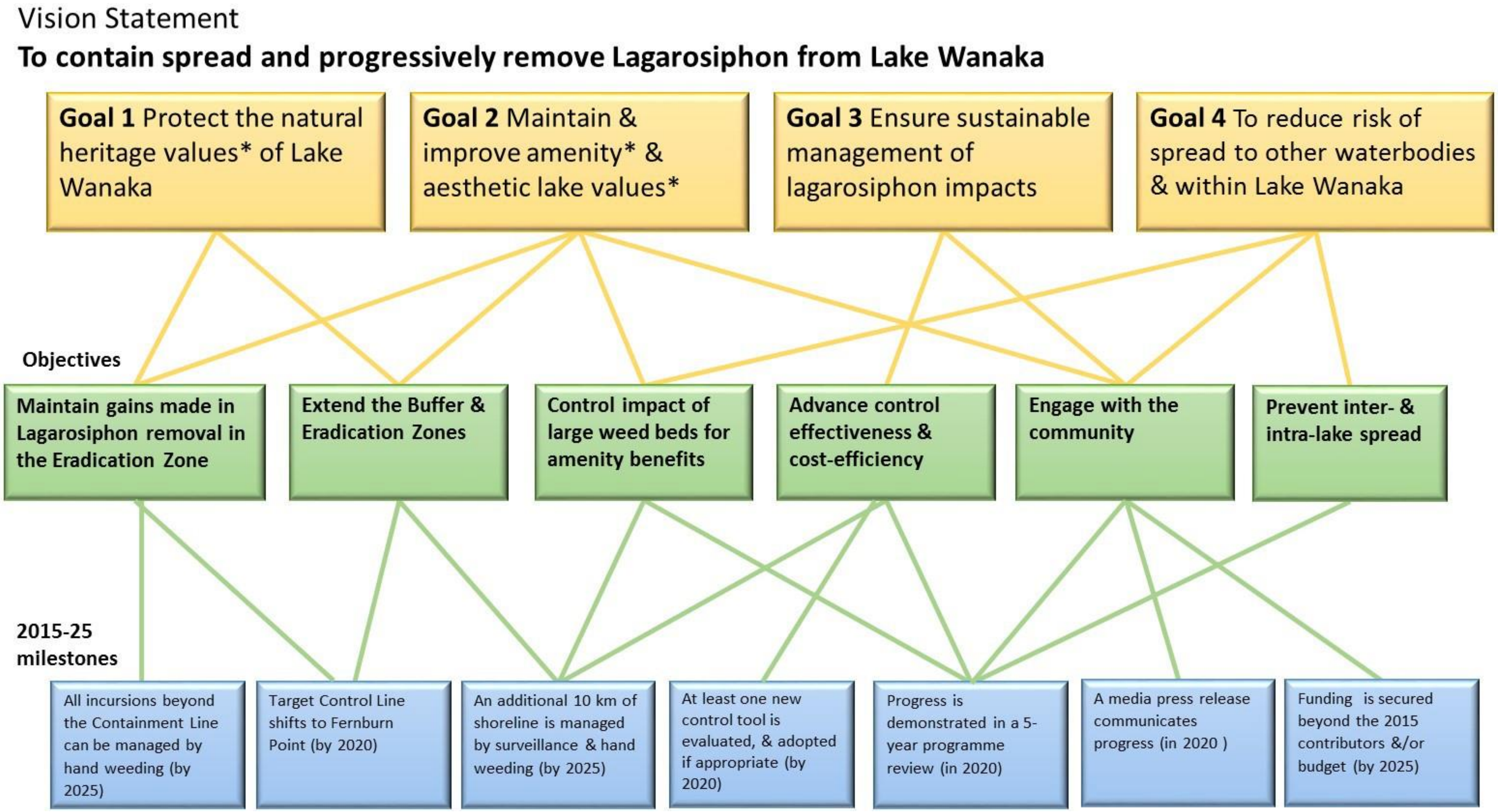
Lake Wanaka is considered a national treasure due to its outstanding natural values. Some of these values are under threat from the incipient risk posed by the presence of *Lagarosiphon major*, one of the worst invasive water weeds in New Zealand.

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 2015 - 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 2015 – 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 2015 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).

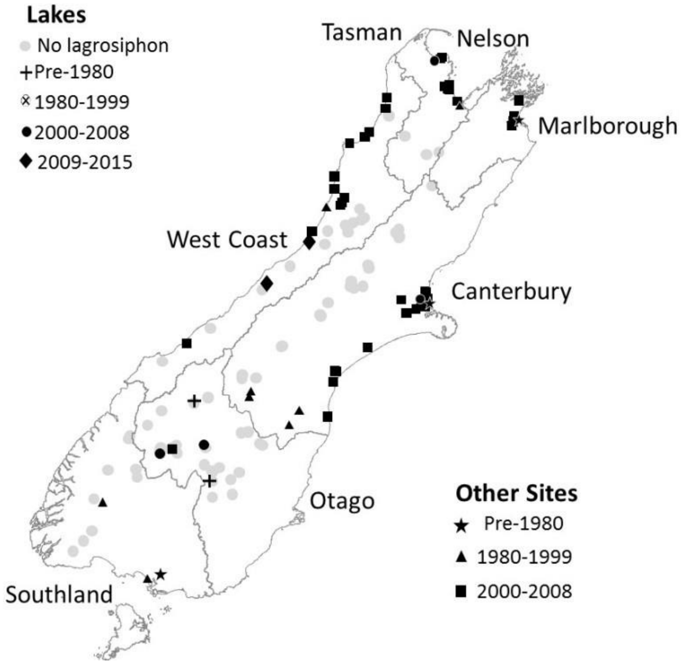


Figure 2: Distribution of lagarosiphon records in the South Island. Note some small sites have since been eradicated. Map modified from de Winton et al. (2009).

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, Colquhouns 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.

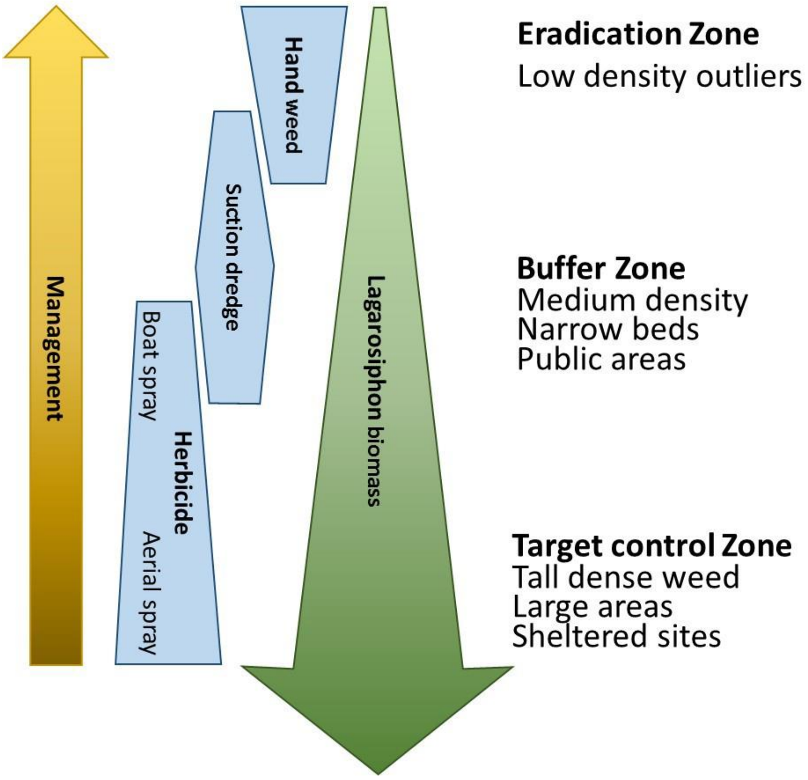


Figure 3: Relationship between feasible control method and lagarosiphon biomass. Right hand text aligns with the methods that are likely to be applicable in the management zones of Lake Wanaka. The directional arrow for management recognises that a shift in method use at a site occurs over time as biomass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

Strategic management zone		Assessment (priority/intensity)	Tactics
Eradication Zone	25 shoreline management units	Low risk No previous records	18 month surveillance, hand weed & record location of outliers
		Historical sites Possible collection points/suitable sites	12 month surveillance, hand weed & record location of outliers
		High risk Recently suction dredged (last 2 years), close to Target Control Zone	6 month surveillance, hand weed & record location of outliers
Buffer Zone	4 shoreline management units	Isolated plants, high risk of re-infestation	6 month surveillance, hand weed & record location of outliers
		Narrow weed bed or isolated clumps	Suction dredge, towards maintenance level
Western Target Control Zone	7 shoreline management units	High biomass weed bed	Diquat spray & follow-up assessment
		Narrow weed bed or isolated clumps	Suction dredge, towards maintenance level
		Amenity control (water intakes, boat ramps)	Suction dredge, hand weed
South-east Target Control Zone*	12 shoreline management units	High biosecurity risk	Diquat spray, suction dredge or hand weed
		Amenity control	Diquat spray

*** Wanaka Marina management is outside of this programme**

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 (2015) 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 (2015), LINZ provide the majority of the budget for lagarosiphon control in Lake Wanaka, with additional contributions from ORC, QLDC and an anonymous donor (2015-2020). 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.

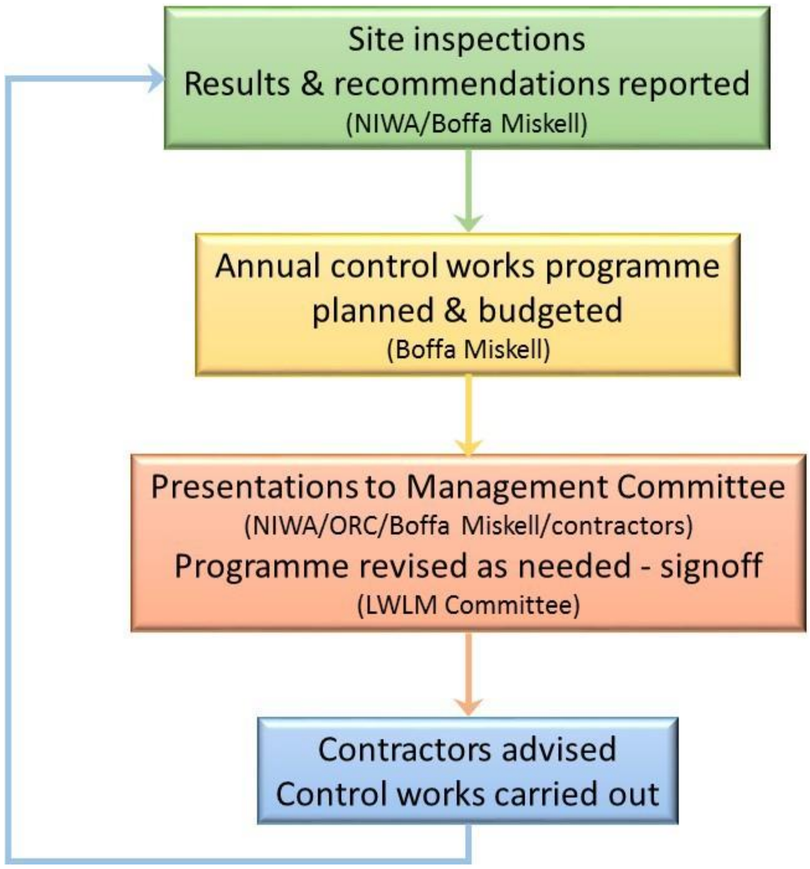


Figure 5: Annual process of planning and review that sets the programme of control works.

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.

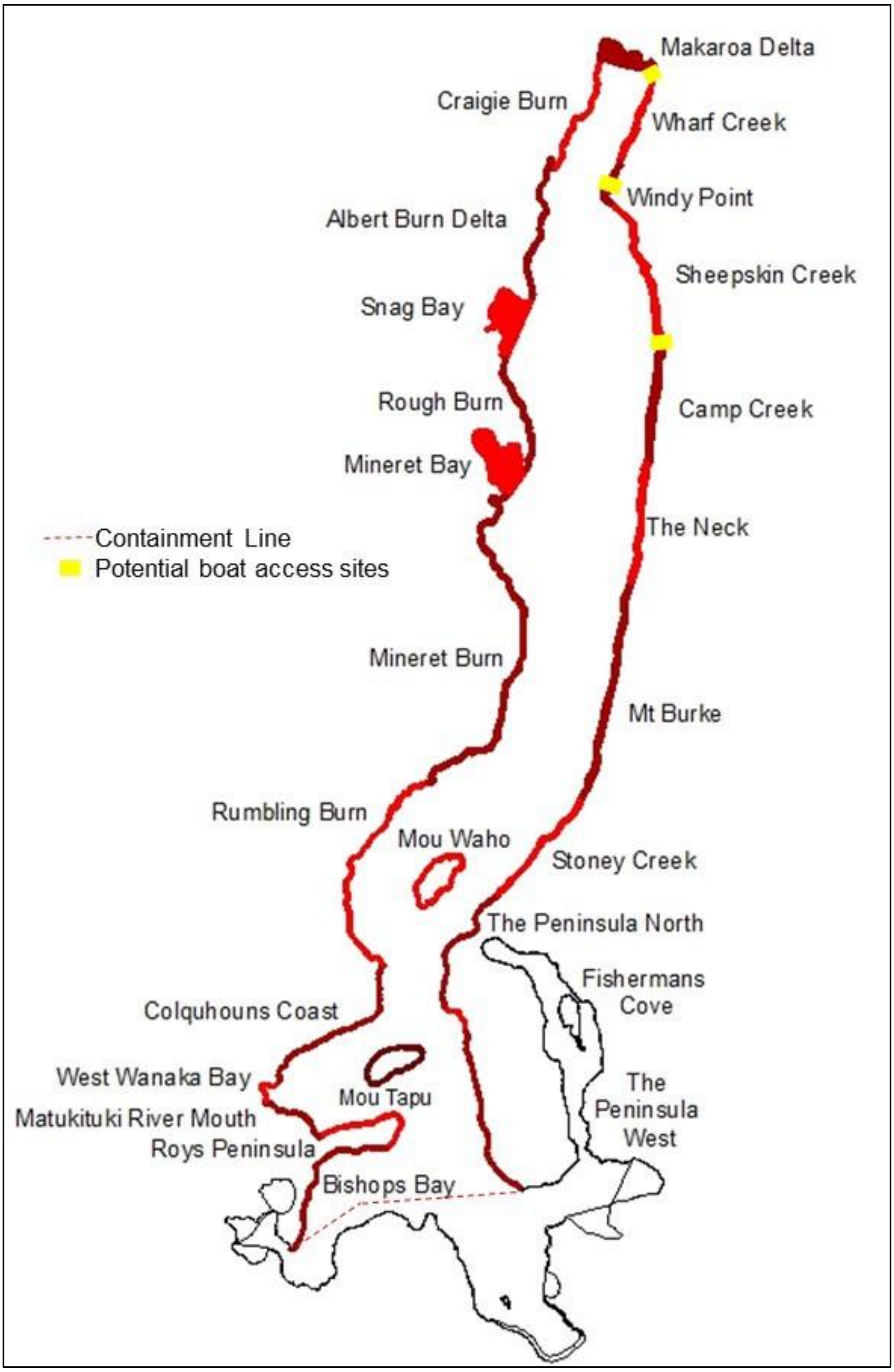


Figure B-2: Map of Lake Wanaka showing strategic and shoreline management units for the Buffer Zone and Target Control Zone. Buffer Lines and Containment Lines separate the Eradication Zone to the north (see Figure A-1), the Buffer Zone to the south, and the western and south-eastern Target Control Zones.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

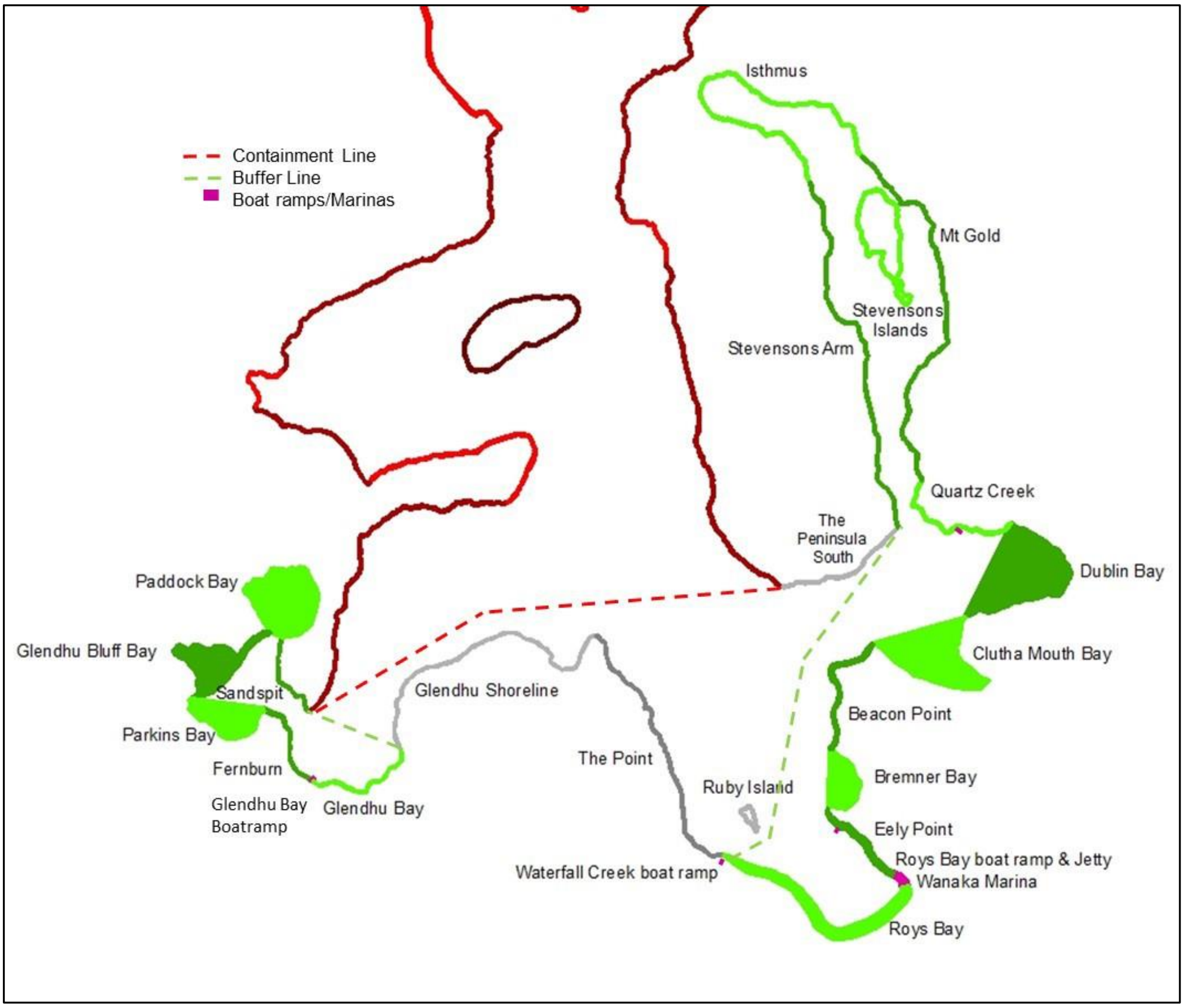
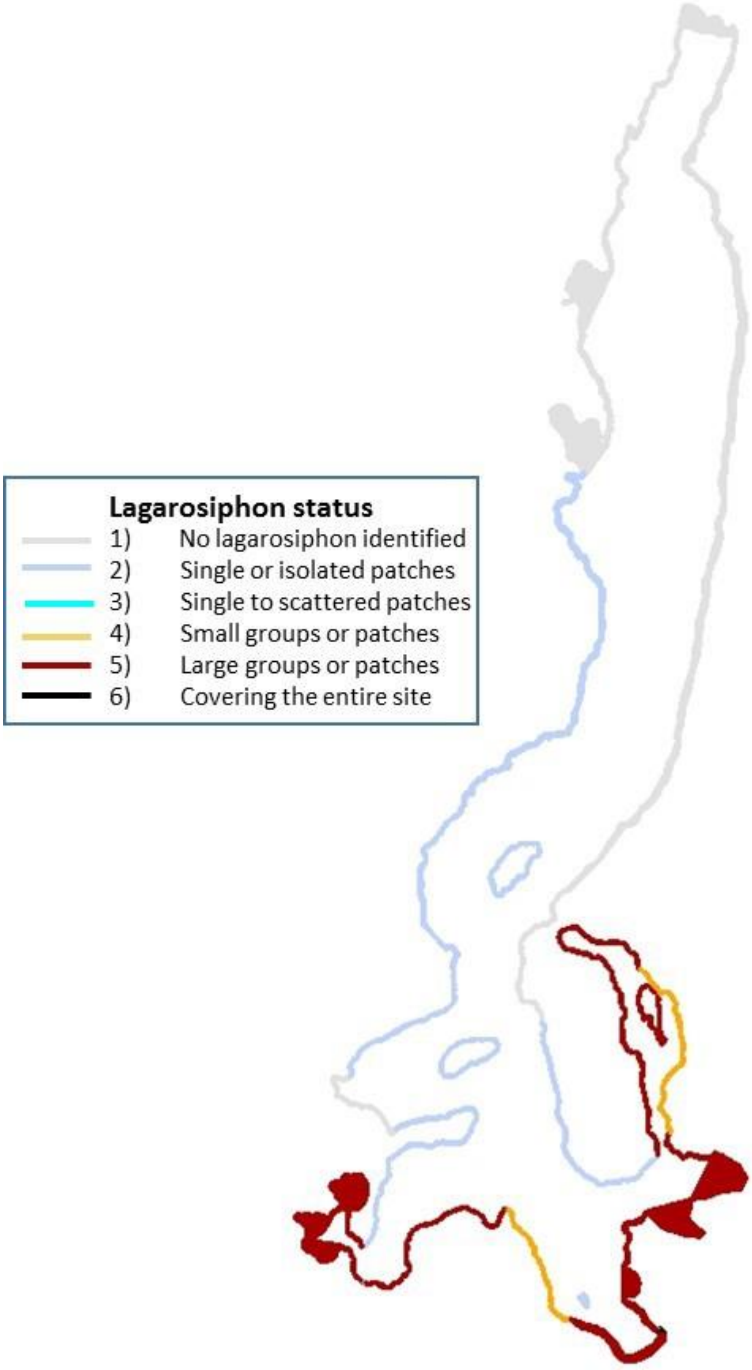


Figure B-3: Status of lagarosiphon density for the 48 shoreline management units in Lake Wanaka, May 2015.



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 m^2, 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

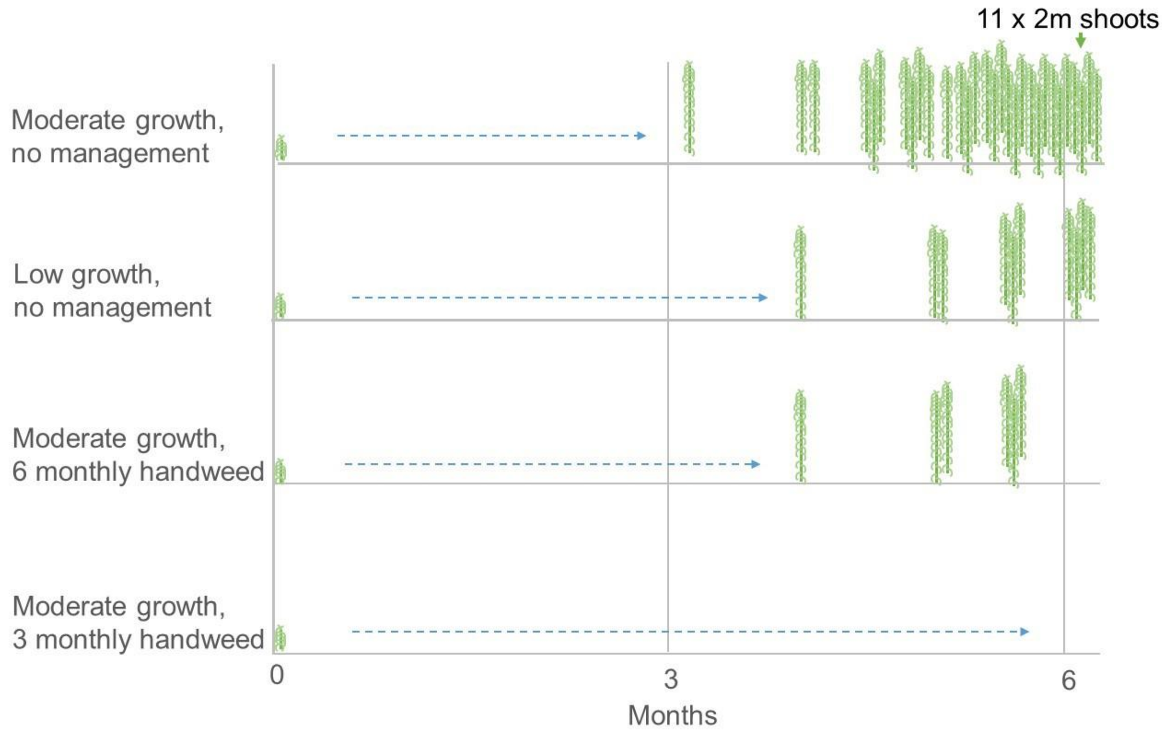
2013: Containment line shifted south, additional 6 km shoreline where eradication feasible

2015: First private funding contribution to the control programme received

Appendix F Lagarosiphon growth scenarios

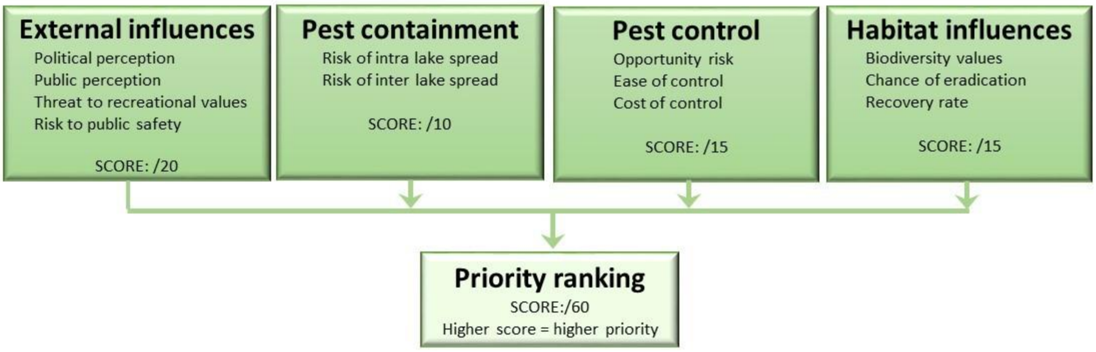
Surveillance frequency and timing is important relative to the establishment of a new fragment. The aim is to find and remove a plant before it generates further fragments. Scenarios of lagarosiphon stem growth, assuming moderate or low growth rate, and the effect of frequency of hand weeding are considered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

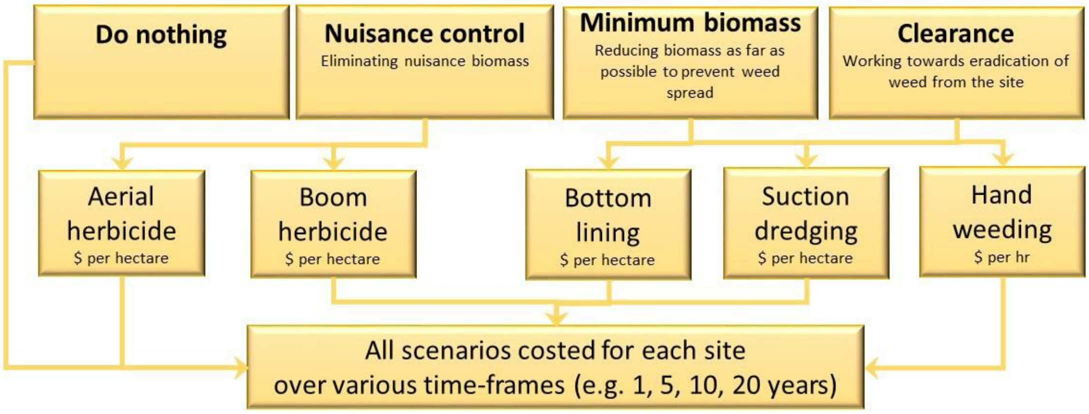


Appendix G Site Prioritisation Model

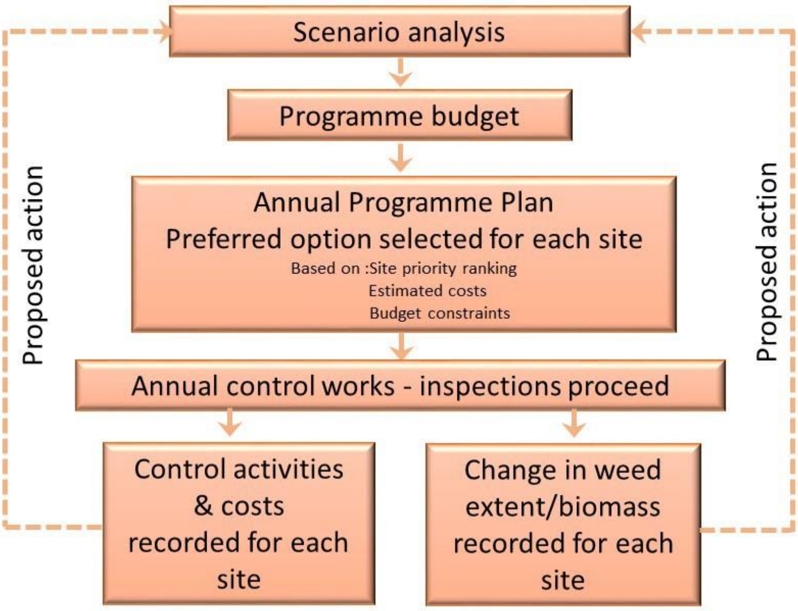
1. Site prioritisation



2. Site control options & costs



3. Planning and evaluation



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NIWA
Taihoro Nukurangi

Management Plan for the Lagarosiphon incursion in the Kawarau River: 2016-2019

Prepared for Land Information New Zealand and Boffa Miskell

June 2016

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Contents

Tables

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Executive summary

The presence of lagarosiphon (*Lagarosiphon major*) in the upper Kawarau River poses a threat to high value waterbodies in the area, including iconic Lake Wakatipu. This threat is recognised by key agencies Land Information New Zealand, Queenstown Lakes District Council and Otago Regional Council who are seeking to combine their efforts to manage lagarosiphon. This Management Plan for lagarosiphon in the Kawarau River identifies a strategy for agencies to combat the threat of lagarosiphon over the next five years.

Lagarosiphon was first recorded in the Kawarau River in 2008 and since that time has shown the ability to expand and form surface-reaching beds in numerous sites. The upper river (c. 4 km below Kawarau Falls Bridge) represents the only habitat for weed establishment in the river, while downstream Lake Dustan is already habitat-saturated by the weed. Several incursions of lagarosiphon detected in Lake Wakatipu were associated with destinations of jet boats returning from the river, in keeping with the role of boating as the major spread pathway for this submerged weed.

In this Management Plan three goals and five objectives are proposed to '*Minimise the risk posed to iconic waters of the Otago Region by lagarosiphon in the upper Kawarau River'.* These outline initiatives to prevent contamination of boats and their role in spreading the weed, actions to roll back the extent of lagarosiphon in the river, and an intention to minimise the impacts of the weed on river users.

Management areas in the upper river have been prioritised for management based on the risk for boat contact and achievable outcomes for lagarosiphon removal (i.e., an upstream to downstream direction for progressive containment). Control tools identified for use against lagarosiphon include hand weeding (low density plants), suction dredging (narrow weed beds), herbicides (larger biomass sites) or cutting (to reduce weed bed height). This plan also recognises possible opportunities to harness river dynamics (i.e., clearance of cut biomass, erosion of weed bed substrates).

There are considerable challenges to controlling lagarosiphon extent and abundance in such a riverine environment, with the application of some control methodologies having limited application or constraints to their use in flowing water. Therefore this Plan emphasises an adaptive management approach, where outcomes are regularly assessed and tactics are adjusted accordingly.

1 Introduction

Lagarosiphon is a significant submerged weed which has the potential to impact on values of New Zealand waterways. The discovery of lagarosiphon in the upper Kawarau River close to Queenstown raises a number of issues around the risk to other, high value waterbodies, and challenges in controlling the weed in this river environment.

It was recognised that a management plan was needed to guide an appropriate incursion response at Kawarau River. This report seeks to identify a common strategy across key agencies comprising Land Information New Zealand, Queenstown Lakes District Council and Otago Regional Council.

2 Higher level strategy

2.1 Vision statement

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

Minimise the risk posed to iconic waters of the Otago Region by lagarosiphon in the upper Kawarau River.

This report recognises that the greatest risk posed by lagarosiphon is not so much for *in situ* values in the river but for the other high value waterbodies of Otago (particularly Frankton Arm of Lake Wakatipu) due to the potential for lagarosiphon to be spread by boat traffic.

2.2 Goals

Three high level goals are identified for 2016 to 2020.

Goal 1: Prevent transfer of lagarosiphon from the upper Kawarau River.

This goal requires a range of initiatives to minimise contact with and transfer of lagarosiphon by boat users of the upper Kawarau River. These include reduction in the biomass of lagarosiphon that boats may encounter and contact. It also covers actions to raise awareness amongst boat users as well as provision of clear protocols for them to follow to remove risk of transfer. It may also involve infrastructure initiatives to aid in boat hygiene.

Goal 2: Contain and progressively reduce lagarosiphon in the upper Kawarau River.

A strategy of allocating resources to priority areas and articulating the outcome sought for each area will enable the most gain in control of lagarosiphon. This report identifies shoreline management units and their prioritisation for control works.

This report also recognises the challenges posed in developing effective control methods and tactics to control and reduce lagarosiphon biomass and extent in the upper Kawarau River. Most control technologies for submerged weeds have been developed and tested for static water lakes, not under flowing water conditions. Flowing water conditions may create difficulties for mechanical control methodologies through presence of snags and hazards for equipment and personnel. It also minimises the critical contact with plants necessary for herbicides to have an effective outcome. This issue mean that adaptive control tactics need to be developed and validated within the infested area.

Goal 3: Minimise the impact of lagarosiphon on recreational and utility values for river users.

The immediate impact of lagarosiphon on river users is low, although there is potential for the extent and biomass of lagarosiphon to increase somewhat over time. Commercial jet boat operations are encouraged to take precautions against lagarosiphon transfer. As yet no areas are cordoned off for biosecurity purposes. We also recognise that the control works themselves may inconvenience river users at times and that the management strategy should seek to minimise this.

2.3 Objectives

To support the goals above, five objectives identify specific intentions of this management plan.

Objective 1: Reduce the upstream extent of lagarosiphon.

Because lagarosiphon colonisation proceeds primarily from upstream to downstream, the greatest gains in reducing the extent of lagarosiphon will be from prioritising areas in the upper river for lagarosiphon control works. These areas are also of greatest proximity to the Frankton Arm, therefore arguably the greater threat.

Objective 2: Trial and confirm effective and cost-efficient control tactics to reduce surface-reaching beds of lagarosiphon in the river.

The lack of guaranteed control methodologies for the lagarosiphon infested river environment means that control works must be carefully applied based on best likely outcomes, and actual outcomes need to be monitored to validate the continuation of the approach. This adaptive management approach means control costs are greater in initial years.

Objective 3: Ensure agency co-operation to maximise outcomes for lagarosiphon management through policies, planning and shared oversight.

This plan recognises that agencies with differing purview can contribute complimentary actions and initiatives towards the management of lagarosiphon in the upper Kawarau River. Because of this it is vital that these agencies share the same understanding and vision.

Objective 4: Secure a longer-term budget (c.10 years) to ensure progressive containment.

This plan recognises that management of lagarosiphon will be a long-term commitment and although we expect a significant reduction in lagarosiphon extent and biomass can be achieved within a few years, if control works cease because of lack of budget, then the gains made will be rapidly reversed.

Objective 5: Raise public awareness through appropriate information campaigns and infrastructure.

Public awareness and adoption of practices to minimise contact with, and transfer of lagarosiphon are vital to containing the weed within the Kawarau River. Initiatives should include a Communication Plan, and public education that reinforces the messages of the Ministry for Primary Industries 'Check Clean Dry' campaign. Additional infrastructural considerations (weed cordons, wash down facilities, siting of boating structures) should be assessed with a view to lagarosiphon interception and containment.

3 Agency responsibilities, policies and plans

Land Information New Zealand (LINZ)

LINZ is the lead government agency and is responsible for the management of the bed of a number of waterbodies and associated weed and pest control programmes. LINZ represents the Crown as owner of the lakebed pursuant to the Land Act 1948.

Queenstown Lakes District Council (QLDC)

QLDC administers the District Plan that regulates land use activities including activities on the shoreline, bed and surface of lakes and rivers. Together with ORC, QLDC is responsible for RMA bylaws and consents in relation to activities and structures on the lake.

QLDC undertakes activities related to 'Waterways Facilities', which includes administration of bylaws and regulations via a harbourmaster service, and promotion of water safety[1]. QLDC also provide for public amenity structures at lakes and rivers, maintains a register of waterway structures and foreshore licences.

Otago Regional Council (ORC)

ORC administers the Regional Pest Management Strategy (RPMS) under the Biosecurity Act 1993 that includes provisions for lagarosiphon control and monitoring. Lagarosiphon is identified in the RPMS as a pest of regional significance that requires action.

4 Background

4.1 Upper Kawarau River

For this plan the upper Kawarau River is defined as the c. 4 km long river reach between Kawarau Falls Bridge upstream, and the confluence with the Shotover River downstream (Figure 1). The area has a section of fast flowing water at the Kawarau Falls, associated with a steep drop in elevation. The section downstream is characterised by shorelines edged by overhanging willows and shallow accretions in the lee of bends. In places along the river bed there are logs and branches remaining following tree fall and willow removal operations.

The defined area stops at the confluence of the Shotover River. From here and downstream to Lake Dunstan there is no available habitat for lagarosiphon weed beds due to the increasingly shallower and faster flowing water and mobility of the river bed.

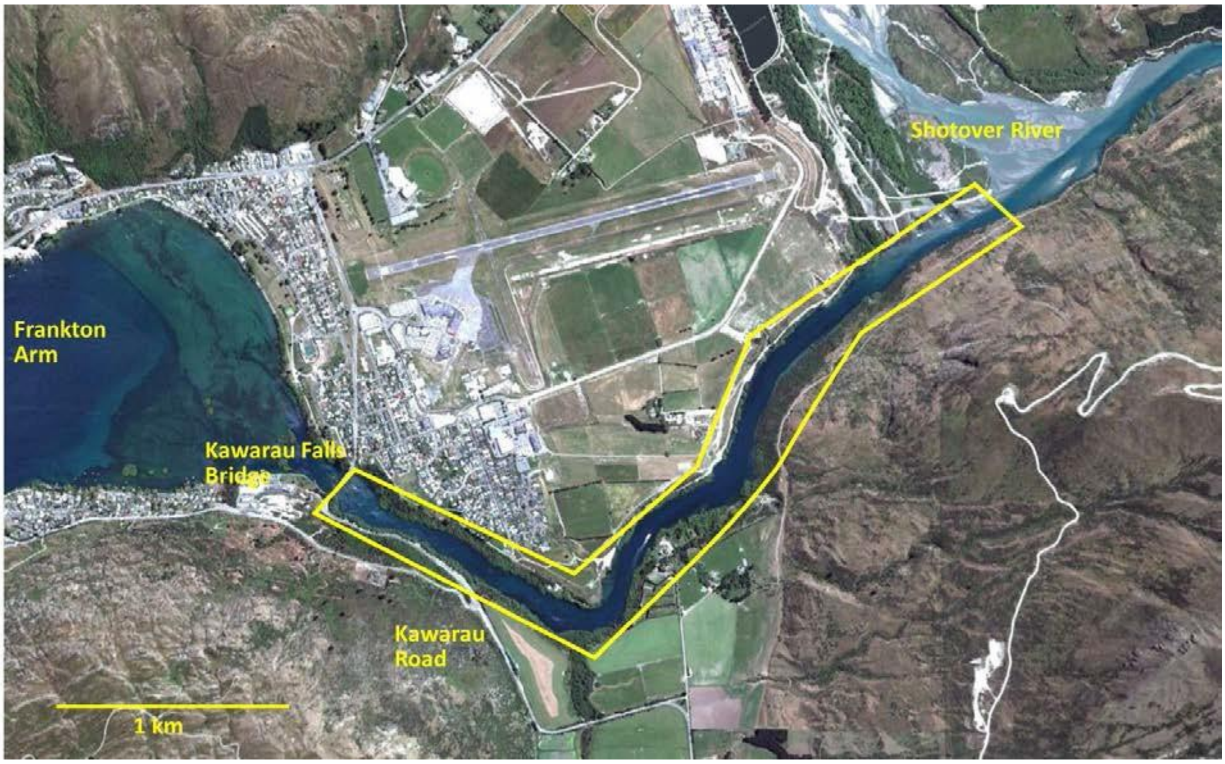

Figure 1: Extent of the upper Kawarau River for the purposes of this plan.

4.2 Lagarosiphon ecology and status

Lagarosiphon (*Lagarosiphon major*), also known as 'oxygen weed', is a submerged, perennial plant of freshwaters. A native of South Africa, it was first reported as naturalised in New Zealand in 1950 and from the Otago Region, in Lake Wanaka, in 1972[2]. The plant has strongly recurved leaves, close-packed and arranged spirally along each stem, being denser at the shoot apex (Figure 2). In weed beds the stems are long, slender, much branched and brittle. Roots can develop from nodes along the stem, which aid in the horizontal spread and colonisation by plants. In older plants, a 'root crown' of hardened stems is found at the base of the plant with roots extending into the sediment.

Reproduction by lagarosiphon in New Zealand is entirely vegetative, with only female plants recorded here. The ability for very 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. To be viable material must include a bud, which are located at the tips of shoots, and at nodes spaced on average every 238 mm of stem length[3]. The size for a fragment to be viable is not confirmed, although 50% of fragments of lagarosiphon were found to regenerate, although their mean length was just 32 mm[4]. Viable apical fragments 250 mm in 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[3].

Figure 2: **Images of *Lagarosiphon major* (reproduced from *Freshwater pests of New Zealand*).**

Human activities are the major factor in the spread of lagarosiphon via accidental transfer between waterbodies on contaminated boating or fishing gear, and also through the cultivation and subsequent release of plants. Although waterfowl have been suggested to spread weed there is no evidence they are a vector for lagarosiphon. Instead lagarosiphon distribution in lakes was significantly associated with boating and fishing activities[3]. In a statistical modelling approach the known distribution of lagarosiphon in New Zealand lakes was best explained by road development and human population densities around infested lakes as measures of recreational access[5].

Lagarosiphon can grow to a maximum depth of 6.5 m, and up to 5 m in height where there is low physical disturbance (waves or flows) and water clarity (light availability) permit. Lagarosiphon beds are unlikely to form within river systems where flow velocity is greater than 0.5 m per second[6] or under frequent large flood flows (e.g., four times the median flow[7]). Beyond the river habitats, lagarosiphon has shown the ability to invade a wide range of lake systems[2].

Currently in the Otago Region, lagarosiphon is present in the Kawarau River, Lake Wanaka, the Clutha River and Lake Dunstan, with records also in Canterbury, West Coast and Southland Regions (Figure 3). However, there remain numerous lakes in the Otago Region that have not been invaded by lagarosiphon (Figure 3).

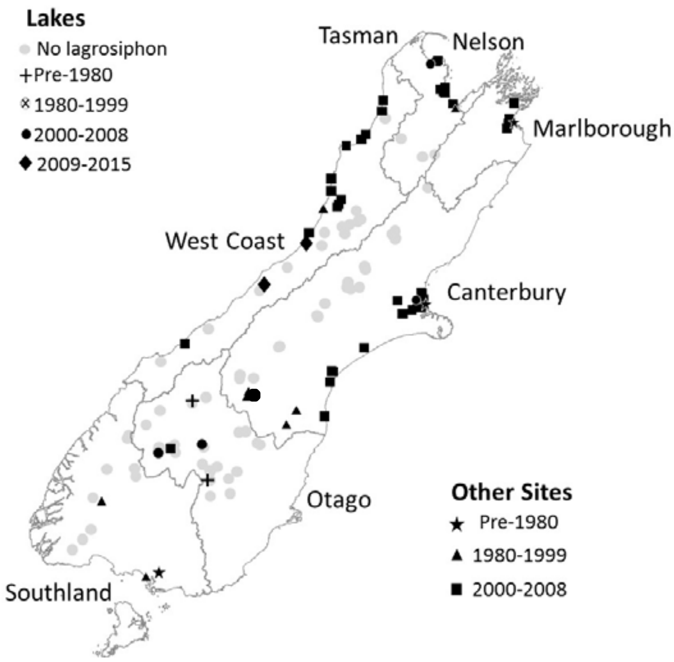

Figure 3: Distribution of lagarosiphon records in the South Island, but note some small sites have since been eradicated. Map modified from de Winton et al. (2009).

New Zealand legislation prevents the sale and distribution of lagarosiphon by way of a cooperative agreement (National Pest Plant Accord) between central government agencies, local government agencies and the Nursery and Garden Industry Association. This has the effect of setting an 'Unwanted Organism' designation for lagarosiphon under the Biosecurity Act (1993). 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.

The Regional Pest Management Strategy for Otago Region[8] designates lagarosiphon as a 'Total Control Species' outside of Lake Wanaka, Lake Dunstan and the Clutha River. This total control status would apply to lagarosiphon in the upper Kawarau River and is taken to mean the prompt eradication of a species. The Operational Plan for the Pest Management Strategy for Otago that covers the period 2009 to 2019[9] 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.

4.3 History, current status and future development of lagarosiphon

Lagarosiphon was first reported in the upper Kawarau River on 6 May 2008 by Marty Black, Harbourmaster for the districts lakes and rivers. A follow-up inspection by NIWA later that month[10] showed lagarosiphon along both sides of the river with the main area of infestation along c. 200 metres of the true right bank and over a width of c. 15 to 20 m (Figure 4). Here lagarosiphon formed over 100 scattered dense patches, 5 m^2 or larger, with 100% total cover and in some places it was almost surface reaching. This shallow site was opened up during willow removal operations and had residual debris of trunks and branches where fragments may have originally been snagged. Lagarosiphon was less widespread on the true left bank but a weed patch was noted on the river bend immediately below the Frankton Zoological Gardens.

An inspection of the upper Kawarau River by Aquateq Ltd contractor Stuart McNaughton in September 2014 estimated the infested area at c. 10 hectares.

An inspection by NIWA in October 2014 showed the lagarosiphon on the true right bank had expanded to form 100% cover bed over an estimated distance of 340 m. Over an additional 150 m upstream of this bed, lagarosiphon abundance decreased to single colonies and plants, apparently transported by back eddies. Elsewhere, narrow beds were noted down to just above the Shotover River confluence in areas where river velocities were slower, shoreline slopes were moderate and overhanging willows did not heavily shade the edge. On the true left bank, upstream of a pump house, the narrow beds formed surface-reaching bands.

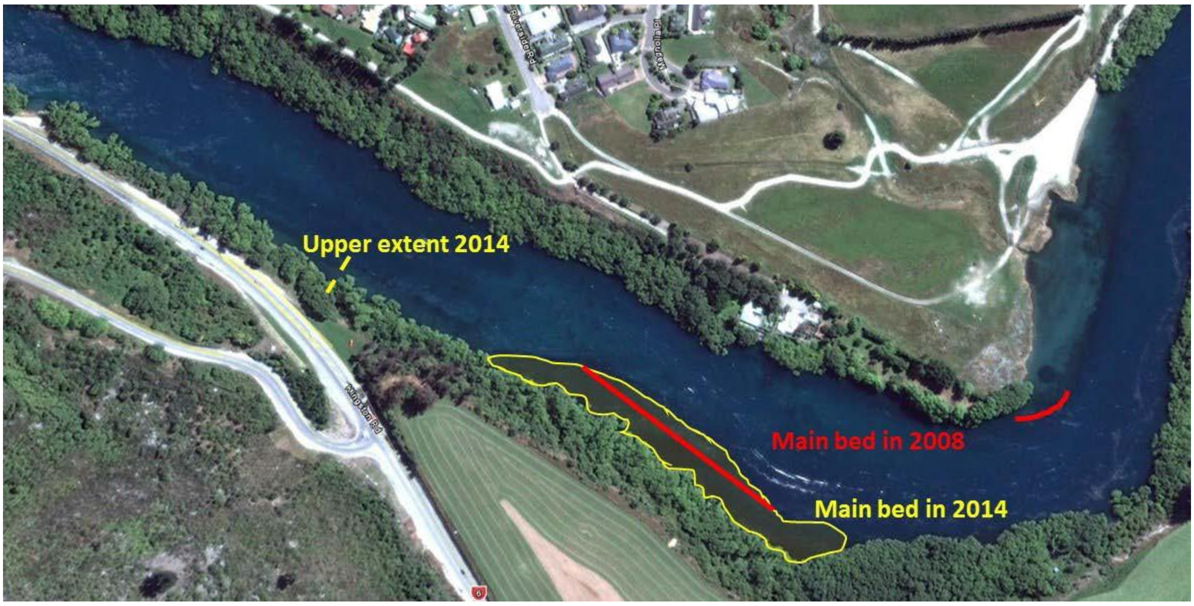

Figure 4: Estimated extent of the main lagarosiphon beds in 2008 and in 2014.

Prior to the initial 2008 river record for lagarosiphon, an incursion was found in the Frankton Arm, Lake Wakatipu by ORC on 23 March 2007. This site was off Sugar Lane, close to the launching and jetty amenities. Initially it was thought to be an introduction via launching of a contaminated boat[11], however in hindsight, the source may well have been the upper Kawarau River. On 10 March 2014 a loose clump of lagarosiphon was found near the main Frankton Marina, which was removed by the contract divers. This was suspected to be from a jet boat coming from the upper Kawarau River. Between 18 and 21 April 2016 lagarosiphon plants were found at the Kawarau Jet Jetty near the lake outlet, the Earnslaw Dry Dock, the Frankton Jetty (near the petrol bowser) and in Queenstown Bay near Thunder Jet. All incursions were removed and an extensive surveillance effort at high use areas of Lake Wakatipu did not detect further plants.

Without control works intervention on lagarosiphon in the upper Kawarau River, it is expected that the upstream extent of lagarosiphon will increase to the foot of the Kawarau Falls, and that weed bed development will continue to expand. Lagarosiphon is a 'transformer' species (see Glossary), capable of altering the environment to better support its growth. Amongst lagarosiphon influences relevant to the upper Kawarau River would be the modification of flow velocity[12], enhanced sedimentation of fine particles within dense beds[13] and increased stabilisation of the river substrates during flushing flows. These processes may serve to increase the area of suitable habitat for lagarosiphon over time and thereby the impacts from its presence.

Velocity measurements in the vicinity of the current weed beds (from top 5-knot buoy down to the elbow) showed flows did not exceed 0.2m sec^{-1} (Jeff Donaldson, Otago Regional Council, Pers Comm., 11 September 2015), with the ambient flows well within the tolerances of lagarosiphon for colonisation.

4.4 Kawarau River and Lake Wakatipu values at risk

This section outlines the impacts of lagarosiphon within the upper Kawarau River. Additional impacts on the regions lakes, in the event of lagarosiphon transfers from this site, are also recognised but are not covered in detail here. For further information see the Ten Year Lagarosiphon Management Plan for Lake Wanaka[14].

The upper Kawarau River is included as one of the 'waters to be protected' in Schedule 2 of the Water Conservation[15]. Outstanding characteristics identified for the wider river include its wild, scenic or other natural characteristics, scientific and ecological values, and quality for recreational purposes. Restrictions and prohibitions for the river include no damming, and for water quality to remain at a standard suitable for contact recreation purposes (sufficient water clarity, no contaminants that render it unsuitable for bathing, no undesirable biological growths as a result of any discharge of a contaminant).

Lagarosiphon development has some implications for recreational use in the upper Kawarau River. Large beds of canopy-forming weeds are associated with depressed quantity and quality of boating, swimming and nearshore recreation[16]. Tracks to the river from the end of Riverside Road are one likely access point for swimmers, which is adjacent to a shallow zone out of the main river flow. This area is also habitat for lagarosiphon. Entanglement and drownings have been linked to invasive weed beds[17], while dense mats of weed provide good habitat for the snail hosts of parasites that cause 'swimmer's (duck) itch'[30], which has been recorded at nearby Lake Wanaka.

Large weed beds and seasonal near-surface development curtail access to river areas for boats, either because of navigation constraints in dense beds, or because of recommended avoidance of these beds as a biosecurity action.

The central business districts in Queenstown are prone to flooding when rainfall events cause a backflow of the Shotover River up the Kawarau River, reducing the head height for drainage of Lake Wakatipu. There has been suggestions that if lagarosiphon was transferred to the Frankton Arm that weed bed development could then retard flows to the Kawarau River and exacerbate flooding.

4.5 Pathways for spread

The major pathway by which lagarosiphon may be transferred from the upper Kawarau River would be by contaminated boats and recreational equipment. Due to the good public access along the river bank collections for aquarium and ponds cannot be discounted but is assessed as a much lower risk.

The upper Kawarau River has a major commercial jet boat industry for tourists, peaking in use around the height of summer holidays. On the whole commercial operators are well informed on extent of lagarosiphon in the upper Kawarau River and the level of transfer risk. They avoid the weed bed areas and carry out an 'engine switch-off' procedure upon returning to Lake Wakatipu under the Kawarau Falls Bridge to allow any weed material entrained to the jet intakes to drop off.

Less is known about the habits of casual jet boaters and jet skis. These river users are more likely to navigate through the lagarosiphon beds for shore access, with greater scope for weed material to be become lodged in jet intakes and grates. Casual launch sites for small boats (jet skis, jet and propeller boats) exist close to the area, including the domain at Kawarau Falls Bridge, off Kawarau Road, from Riverside Road below the elbow and the delta at the mouth of the Shotover River. Use of these sites may increase the risk of boat and trailer contamination.

5 Control methodologies

The identification of an appropriate control methodology for lagarosiphon is strongly dependant on the site characteristics, the status of the weed and the outcome sought within the upper Kawarau River.

Hand weeding is where snorkel/scuba divers remove individual lagarosiphon plants. 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.

Hand weeding is an appropriate control method in situations where a target weed can be easily found (e.g., sufficient water clarity) and is distributed at a low density of <125 shoots per 0.1 ha[18], or where patches do not exceed 1 m^2. It is not practical once infestations expand, as it becomes a very labour intensive method. It is also limited in effectiveness if there is constant seeding of fragments into the area (e.g., from an upstream source). Hand weeding has been used in the US[18], Ireland[19] and Lakes Wanaka, Waikaremoana and Benmore.

A **suction dredge** or diver-operated Venturi suction pump results in the dislodgement of plants and removal via a suction tube. Either plants can be collected in a fine mesh collection bag within a floating barge[20] or potentially mulched to ensure the majority of fragments are no longer viable and released back to the river. The latter is more cost effective as it does away with the need to off-load and dispose of bulky weed.

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[21]. It is also difficult to work around underwater obstacles such as fallen trees, which are an issue at the edges of the upper Kawarau River. Up to 20 days labour per ha is likely for dense weed beds, but effort may be reduced by targeted use of herbicides (see below) to reduce the standing biomass. 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[22]. Suction dredging has been used to eradicate submerged weed from a 610 m length of river in Texas, USA[23] and to remove large lagarosiphon beds in Lakes Waikaremoana, Wanaka and Benmore.

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[24,25]. 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 within the upper Kawarau River.

Diquat is a widely used herbicide[20] that is relatively fast acting[26]. 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 gun and hose, by boat using surface booms or subsurface injection via trailing hoses or booms. These methods are likely to be appropriate for river environments. Helicopter application is only appropriate for large areas under suitable weather conditions and where obstacles (e.g., willows) are not in the flight path.

Diquat use in Otago Region is a permitted activity. 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[24]. 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[27] 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[24]. 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[28].

The advantage of endothall (di-potassium) 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[29]. Further research to evaluate endothall as a potential control tool in large lakes or in flowing water is required before this option could be recommended.

In general terms, improving herbicide performance in flowing-water environments is recognised as a research priority internationally[30] given the lack of information compared with herbicide use in static waters. However, publications where either diquat or endothall have been used to control submerged aquatic weeds, other than lagarosiphon, in flowing systems indicate that efficacy can be obtained through combinations of slow release application techniques and product formulation to maximise the exposure time of the target weeds to the herbicide[31,32,33,34].

Cutting refers to the severing of stems within a weed bed to reduce biomass near the water surface. Weed cutters are best used on a small scale where weed beds are narrow or small in extent. It is also appropriate where the habitat is already saturated by lagarosiphon propagules, or where there is little or no downstream habitat for weed growth. Mechanical cutting is possible from a boat using a cutter bar of reciprocating blades. Cut material may be left to disperse (e.g., in flowing water), raked out, or moved into deeper water. Cutting is usually limited to 1-2 m below the water surface and substantial biomass can be left behind, therefore recovery from the remaining material can be rapid. Cutting is best carried out at the beginning of the growth season (October-November) before bulk weed development, and repeated regularly during the summer and autumn to prevent near-surface growths. Effective control could be short-lived (1-2 months) over the growth season, especially under good weed growing conditions (e.g., high water clarity).

6 Defining areas and priorities

Nine shoreline areas are defined as management units (Figure 5) for lagarosiphon control in the upper Kawarau River. These are labelled in priority order for treatment from 1 (highest priority) to 9 (lowest priority). Priorities recognise the level of risk for boat transfer of lagarosiphon, as well as the gains that can be made in an upstream to downstream clearance sequence for lagarosiphon.

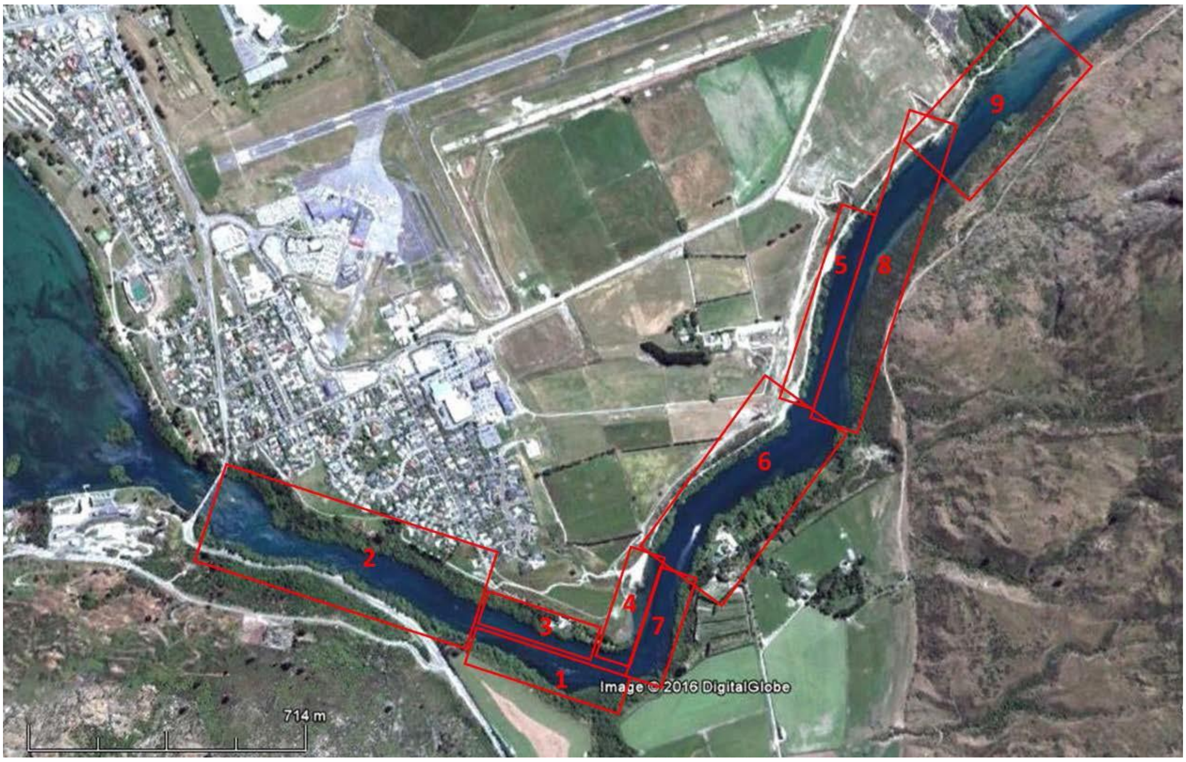

Figure 5: Shoreline management units for lagarosiphon in the upper Kawarau River.

Priority area 1 encompasses the large weed bed (c. 1.5 ha) on the true right bank above the elbow (500 m shoreline). This site is a high priority because of seasonally surface-reaching weed which is of high risk for boat pick-up and transfer. It also represents a large lagarosiphon biomass source that will seed to downstream habitat for the weed. The major aim is to prevent weed at the surface for boat contact during peak seasonal recreation.

Priority area 2 (1850 m shoreline) recognises slow upstream creep by lagarosiphon will increase the proximity of the infestation to the Frankton Arm and therefore increased risk of transfer. This zone is likely to have lower biomass of lagarosiphon where continued removal is likely to achieve local eradication.

Priority area 3 (440 m shoreline) has limited habitat for lagarosiphon on account of overhanging willows. Longer term gains from removing lagarosiphon could be achieved subsequent to removal in Zones 1 and 2.

Priority area 4 is on the true left bank, where a weed bed (c. 0.3 ha) is located around the point and narrows toward the fringe of overhanging willow at its downstream point (380 m shoreline). The site also affords public access to the river and tracks from the end of Riverside Road and is likely to be a pick-up/drop-off spot for boats. This area is of lower priority because 5 knot navigation buoys constrain navigation of boats to the true right, away from this area. Again an aim would be the reduction of surface reaching growth prior to peak summer boat traffic.

Priority area 5 (670 m shoreline) has a narrow weed bed that can be surface reaching. While it would be difficult to achieve a long enough contact time for an effective diquat outcome, repeated cutting would provide seasonal respite from surface growths.

Priority area 6 (1344 m shoreline) has much of the shoreline occupied by willows that overhang the river, reducing available habitat for lagarosiphon. It has access ways along the shoreline which increases its priority slightly. Apart from control of any surface reaching beds, control works in this zone would be low priority unless substantial clearance has been made down to this point.

Priority area 7 is primarily flanked by willows and may receive higher flows being on the outer bend. This area should be addressed at a similar priority to area 6, but has slightly lower risk for boat contact with weed beds.

Priority area 8 is downstream on an outer bend of the river. Lagarosiphon abundance is likely to be restricted here and the site can be left at lower priority unless narrow surface reaching beds develop that require cutting.

Priority area 9 is lowest priority. Only part of this area is likely to support lagarosiphon and gains are small unless a substantial reduction in lagarosiphon can be achieved upstream.

7 Management approaches for shoreline units

Table 1 summarises a staged approach to the progressive containment of lagarosiphon by providing possible steps over 5 years. Due to the uncertainty of control outcome we suggest a review after 5 years of the priorities and aims for the shoreline units, progress and future actions.

7.1 Herbicide

The herbicide diquat may achieve a reduction in height and biomass of larger weed beds in areas 1, 3 and 4, however, some investment will be required initially to confirm the best application strategies for a successful outcome.

Based on current knowledge, applications should include a gelling agent to aid in herbicide placement and rhodamine dye in order to trace water movement that will disperse the diquat. Thought should also be given to ways of placing the diquat within the weed bed to achieve a long enough concentration-contact time for an effective control outcome. Use of gun and hose is a recommended method to treat the inner part of the bed against the shoreline without disturbing surface-reaching vegetation. One option for the outer part of the bed may be to maximise the treatment area so that flow-through of treated water is sustained. For instance, at a river velocity of 0.2 m sec^{-1} diquat application of 720 m length of shoreline will theoretically provide the downstream point with a 1 hour contact time for herbicide. Alternatively, a dosing or repeated application of herbicide could be made to compensate for water movement. Of these approaches a trickle feed application is considered the most promising. It would involve an initial investigation to maximise the configuration of lines and nozzles (i.e., spacing, depth of release) according to flow velocities through the bed. This could be achieved using dye release and results used to guide an actual application.

Suitable river conditions for herbicide application would be low flows/water levels, minimal turbidity, as well as good plant condition (i.e., clean and healthy, active photosynthesis).

For herbicide costings in Table 1 we have included application costs and material costs for product, gel additives and rhodamine dye with an overall indicative costing of c. $2,000 per ha (cost depends on area treated). The suggested budget (Table 1) allows for multiple herbicide applications in initial years and assessments of outcome in order to validate an approach. If sufficient biomass reduction can be achieved then suction dredging may become feasible to sequentially remove the bed in an upstream to downstream direction (Table 1).

7.2 Surveillance and hand weeding

Table 1 includes, as an early action, the delimitation of lagarosiphon in shoreline unit 2 to confirm the current upstream spatial extent of lagarosiphon and proposes hand weeding to remove it in an upstream to downstream direction. This would be an ongoing action but the level of effort should decrease over time until only a basic maintenance effort is required annually. Hand weeding would also follow progress achieved by suction dredging of weed beds.

7.3 Suction dredging

Suction dredging should be pursued as an action to follow significant reductions in lagarosiphon biomass by successful herbicide outcomes (Table 1). Suction dredging can be staged over time in an upstream to downstream direction. As for herbicide, there are benefits to matching suction operations to times of low flows/water levels, and low water turbidity for ease and safety.

7.4 Cutting

Cutting is best applied as a solution for narrow surface reaching weed beds to reduce the risk from surface-reaching beds. Although there are no sensitive areas for lagarosiphon establishment downstream (existing status as 'habitat saturated'), this practise needs to be mindful of the generation of floating fragments that boats may encounter. Therefore it is not a suitable control method for high biomass beds and the timing of works should be outside of peak river usage on a seasonal (i.e., avoid peak summer) or time basis (i.e., late in the day).

7.5 Harnessing river processes

The river environment is a dynamic system of sediment transport and deposition and there is a possibility of harnessing these processes to aid in lagarosiphon clearance. Creation of a large depression in river sediments at the upstream end of a lagarosiphon bed may promote a scour face that then migrates downstream, eroding the weed bed in its path. Such a depression might be created using a suction dredge or explosives. If trialled, this action would most logically follow biomass reductions achieved by herbicide use, when the modifying influence of the lagarosiphon bed on flow velocity is reduced.

8 Other management initiatives

Beyond control works in the upper river, there are additional initiatives that can reduce the risk of lagarosiphon spread from this site.

A rationalisation of the casual launch sites in the vicinity of the upper Kawarau River should be made, although some access for launch of rescue boats to the area must be provided for. Closure of sites can be achieved by blocking vehicular access.

Biosecurity considerations need to be embedded in planning responses for future developments in the upper Kawarau River. Any development that opens the river to additional boat traffic, or that increases the proximity of boat haul out areas to the infestation should be carefully considered and, if appropriate, mitigation measures addressed in the planning permission.

The practices of commercial jet boat operators should be informed by the progressive containment of lagarosiphon. As the upstream extent of lagarosiphon is reduced so should the location of the 'engine switch-off' protocol, so as not to reseed lagarosiphon in the upper river.

Currently a 5-knot speed limit is set for the true right bank in the vicinity of shoreline units 1, 3 and 4. This will contribute to avoidance by boats of the weed bed in area 1. A further possibility is the creation of a no-go area around surface reaching beds by buoying them off.

Establishment of weed cordons at public boat ramps in the Frankton Arm of Lake Wakatipu would be a good investment against multiple weed sources, including lagarosiphon from Lake Wanaka or Lake Dustan. These structures are the first line of defence where contaminated boats or trailers enter or exit a lake and they also raise public awareness on weed issues. Cordons also provide a defined area for weed surveillance. Cordon could extend around major boating infrastructure adjacent to Sugar Lane, such as the refuelling jetty where a lagarosiphon incursion has previously occurred. Cordons could also be made a requirement of future marina developments.

Configuration at boat ramps can consider biosecurity as well as safety. Provision of staging areas, where boats can be safely prepared for launching or for road transport should also display signage detailing biosecurity protocols. The provision of boat wash down facilities are another mechanism of increasing weed awareness, but risk from run-off of water conveying fragments to the waterbody needs to be considered if contaminated craft are cleaned on site prior to launching.

Currently ORC has a lagarosiphon surveillance programme that covers lake sites of high risk (e.g., Frankton Arm, Kingston Marina, Glenorchy, Lake Moke). This surveillance is another important measure to contain the spread of lagarosiphon.

Advocacy should provide the public with information that enables them to adopt behaviours that will minimise transfers of freshwater pests like lagarosiphon. Aligning with existing campaigns, like the 'Check, Clean Dry' initiative of the Ministry for Primary Industries or Weed Busters, will maximise the message.

Table 1: **Suggested sequence of control per shoreline unit over the next 5 years to ensure progressive containment of lagarosiphon in the upper Kawarau River.**

Shoreline unit	Aim	Year 1	Year 2	Year 3	Year 4	Year 5
1	Prevent surface-reaching beds, reduce biomass	2 x herbicide ($6k for 3 ha =$12k) 2 x follow- up assessment ($1k ea =$2k)	Herbicide ($6k for 1.5 to 3 ha)	Herbicide ($6k for 3 ha) Suction dredging* ($10 k)	Suction dredging*($10 k)	Surveillance, hand weeding ($5k)
2	Delimit, reduce upstream extent	2 x surveillance, hand weeding ($10k)	1x surveillance, hand weeding ($5k)	1x surveillance, hand weeding ($3k)	1x surveillance, hand weeding ($2k)	1x surveillance, hand weeding ($2k)
3	Delimit, reduce upstream extent	2 x surveillance, hand weeding ($5k)	1 x surveillance, hand weeding ($3k)	1 x surveillance, hand weeding ($2k)	1 x surveillance, hand weeding ($0.5k)	1 x surveillance, hand weeding ($0.5k)
4	Prevent surface-reaching beds, reduce biomass	2 x herbicide ($2k for 1 ha =$4k) 2 x follow- up assessment ($1k ea =$2k)	Herbicide ($2k for 1 ha) Suction dredging* ($10 k)	Suction dredging*($5 k)	Surveillance, hand weeding ($5k)	Surveillance, hand weeding($3k)
5	Prevent surface-reaching beds	Cutting ($2.5k)	Cutting ($2.5k)	Cutting ($2.5k)	Cutting ($2.5k)	Cutting ($2.5k)
6	Prevent surface-reaching beds	Cutting ($2.5k)	Cutting ($2.5k)	Cutting ($2.5k)	Cutting ($2.5k)	Cutting ($2.5k)
7	Prevent surface-reaching beds				Cutting ($2.5k)	Cutting ($2.5k)
8	Prevent surface-reaching beds					
9	Prevent surface-reaching beds					
	Total cost	**40**	**31**	**31**	**25**	**18**

*Dependant on successful biomass reduction

9 Annual operational plans

Adaptive management will be provided for by the annual operational plan, following the process in Figure 6. Important to this process is an assessment of outcomes achieved by the previous control works. Progress needs to be compared to the goals and objectives of this plan, moderated by the available annual budget, and the information used to formulate a draft annual operational plan. This plan is then finalised following approval by the three key agencies.

Figure 6: Process to set the annual operational plan for the upper Kawarau River.

10 Acknowledgements

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11 Glossary of abbreviations and terms

Delimit/delimitation	Determining the spatial extent of a pest species.
Photosynthesis	The process by which plants turn light and carbon into plant tissue and oxygen.
Transformers	Alien invasive species that severely modify and structure the systems that they invade, so named for their transformative detrimental impacts on aquatic ecosystems.
Weed cordon	A netting enclosure designed to allow boat passage (navigational exit/entry point buoyed and lit) but to contain weed fragments that fall off boats during launching or retrieval or temporary mooring.

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