



LAKE WĀNAKA LAGAROSIPHON MANAGEMENT PLAN 2025-2035



Purpose statement:

This plan presents a shared vision for management of the aquatic weed lagarosiphon (*Lagarosiphon major*) in Lake Wānaka. It is envisaged that this plan will be a communication tool within and between the Aquatic Weed Management Committees for key waterbodies. While primarily presenting information for the Lake Wānaka Aquatic Weed Management Committee, the plan also informs the communities that will be impacted by weed in their lakes.

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1 Purpose of the lagarosiphon management plan

This Management Plan seeks to present a shared vision of the lagarosiphon (*Lagarosiphon major*) management for stakeholders, including those with statutory responsibility but also the communities that will be impacted by weed in their lakes. Ownership of this plan by stakeholder groups with a vested local interest raises opportunities for co-ordinated and resourced responses to the weed problem that act beyond the immediate purview of the Toitū Te Whenua Land Information New Zealand (LINZ) Aquatic Weed Management Programme.

Although the plan has considerations that are specific to the site being managed, there is a strong need to consider the bigger picture, enabling a strategic management approach across multiple waterbodies or regions. This is because biosecurity risks, budgetary considerations, legal and regulatory influences act at wider geographic scales than the immediate aquatic weed management site. Therefore, it is envisaged that this plan will be a communication tool within and between the committees for key waterbodies.

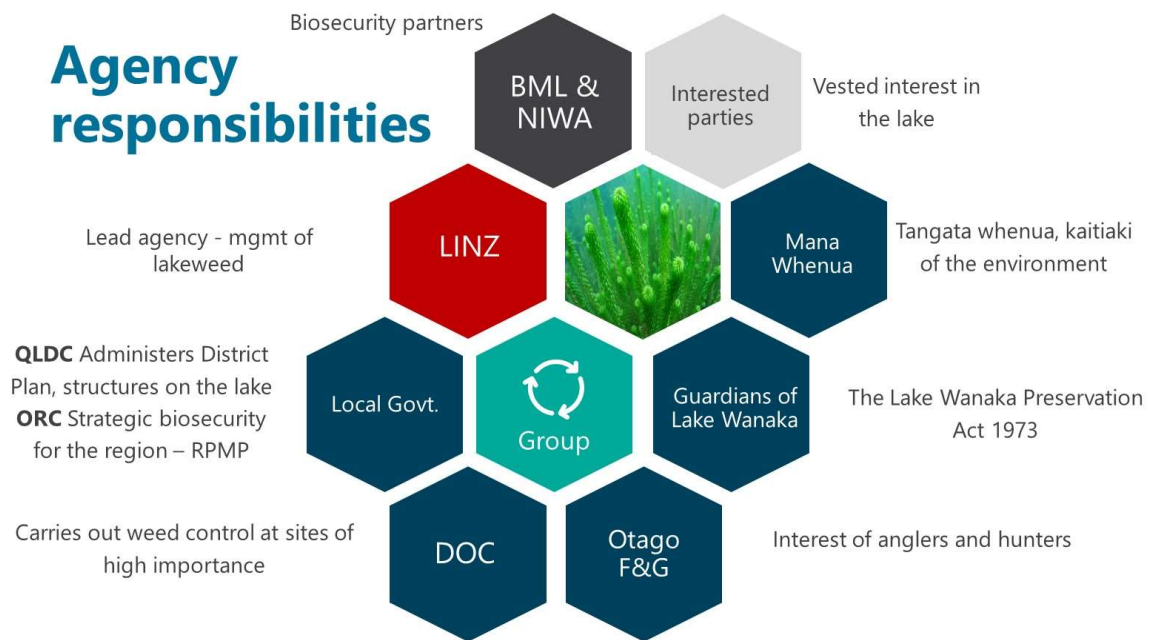
This plan supports evidence-based management, drawing on current knowledge of the systems and science. It considers a ten-year period, however, recognises that regular review will be required and if necessary, the goals, objectives and milestones should be amended as appropriate.

1.1 Stakeholder responsibilities and interests

1.1.1 Lake Wānaka Aquatic Weed Management Committee

Terms of Reference

LINZ has developed Terms of Reference (TOR) for each of the stakeholder groups contributing to the management of lagarosiphon at key sites. These lay out the title of the stakeholder group, their purpose, operating principles, authorisation and consultation expectations, meetings and reporting to the group. The TOR make the differentiation between agencies for which consultation is a key function and stakeholders (interested parties) for whom the key need is communication of information.



Agencies and stakeholders represented in the Lake Wānaka Aquatic Weed Management Committee (Source: J. Percival, LINZ).

Agencies

[Toitū Te Whenua Land Information New Zealand \(LINZ\)](#)

LINZ is responsible for managing Crown-owned land administered under the Land Act 1948 as well as other legislation. This includes the beds of a number of waterbodies such as lakes and rivers. As a result, LINZ lead a comprehensive aquatic biosecurity control programme on lakebeds across New Zealand with operations that specialise in aquatic weed management, mapping, monitoring, and surveillance of weeds. The LINZ biosecurity and biodiversity strategy[i] (2021- 2031) guides priority-setting and investment decisions and Lake Management Plans such as this one guide operations on specific lakes.

[Otago Regional Council \(ORC\)](#)

ORC administers the Regional Pest Management Plan, 2019-2029 (RPMP) under the Biosecurity Act 1993, which sets out the framework for how pest plants and animals specified in the plan will be managed in Otago Region over the next 10 years. ORC is also involved with surveillance of organisms of interest, community assistance, public education and biodiversity projects.

[Department of Conservation \(DOC\)](#)

The primary role of DOC under the Conservation Act 1987 is to advocate for the protection of indigenous freshwater species and fish habitat, on and off public conservation land. DOC also supports agencies and Ministry for Primary Industries (MPI) by advocating under the Biosecurity Act 1993 and supporting containment and management of threats and pests. A main aim is the containment of aquatic pests including three pest fish species and hornwort (*Ceratophyllum demersum*) which have the highest potential to expand to regions where they are not present¹.

Queenstown Lakes District Council (QLDC)

QLDC administer the District Plan that regulates land use activities including activities on the shoreline, bed, surface and catchments of Lakes Hāwea, Wānaka and Whakatipu. Together with ORC, QLDC is responsible for RMA bylaws and consents in relation to activities and structures on the lake.

Guardians of Lake Wānaka

The Lake Wānaka Preservation Act 1973 defines the responsibilities of the Guardians of Lake Wānaka. These include preserving the lake level and shoreline in their natural state and advising the Minister of Conservation over Lake Wānaka related issues including those affecting the recreational use of the lake. The Guardians and ORC liaise over matters which may affect the lake, (including water quality) with ORC and QLDC undertaking consultation over resource consent applications which may affect the lake.

Mana whenua

Kāi Tahu are tangata whenua within Otago and have a responsibility as kaitiaki of the environment. Their cultural, spiritual, historic, and traditional association to Lake Wānaka is acknowledged by the Crown. Consultation has been sought with the Kaitiaki Rūnanga throughout the development of the plan.

Wanaka Marina Limited

Wanaka Marina Ltd undertake submerged weed control works extending 50 m around the Marina. Generally, weed control works are synchronised with activities under the LINZ programme for maximum effectiveness.

Fish and Game Otago Region (Fish and Game)

Fish and Game is the statutory manager for sports fish and game, with functions conveyed under the Conservation Act 1987, with the resource managed defined and protected under the Conservation Act and the Wildlife Act 1953. An affiliation of 12 regional Councils and one national Council, together represent roughly 140,000 anglers and huntersⁱⁱ.

Interested parties

Harbour master

The role of the QLDC appointed harbourmasterⁱⁱⁱ is education and ensuring users of lakes and rivers adhere to relevant water safety rules and bylaws. QLDC contractor, Cougar Security Group, work closely with Maritime NZ, the national safety regulator for recreational and commercial activity on the country's waterways.

Water Action Initiative Wānaka (WAI Wānaka)

WAI Wānaka is an organisation established to accelerate community action for fresh water in the Upper Clutha Catchment. By driving research and monitoring, WAI Wānaka promotes healthy ecosystems and community wellbeing for future generations. A community Catchment Plan identifies Ecosystem Actions that include education campaigns and advocacy for invasive species such as lagarosiphon.

[Check, Clean, Dry representative](#)

The Ministry for Primary Industry (MPI) advocate the Check, Clean, Dry method for preventing the spread of freshwater pests between waterways by human activities. MPI may provide a representative or that role may be completed by another agency.

[Wānaka Yacht Club](#)

Membership to this sporting club affords access to facilities and resources including lake side access and launching ramp at Roys Bay.

2 Background

2.1 Lagarosiphon ecology

Lagarosiphon is only found submerged in freshwaters, where it grows attached to the bed of lakes and river/stream to water depths of c. 6 m and can reach a height of 5 m in deeper water. This water weed is not native to Aotearoa New Zealand. It is native to South Africa and first recorded in New Zealand in 1950^{iv}.



Identifying lagarosiphon

Lagarosiphon is recognised by the leaves, which are curved down and arranged spirally along each stem. The rounded shoot tip of close-packed leaves is also distinctive.

Plants have a base or 'root crown' of fused stems with multiple shoots above and unbranched roots below. Shoots branch from buds at points along the stem. The true roots cannot reproduce and grow.

Tiny female flowers can develop on fine stalks towards the shoot tip, but no seed is known to form in New Zealand.

Lagarosiphon grows year-round and invades a wide range of freshwater systems in New Zealand. It forms large weed beds at shorelines that are sheltered^{v,vi} and where there are low levels of physical disturbance (waves or flow velocities^{vii,viii}) and sufficient water clarity (light availability). Bands of weeds and scattered colonies are more restricted along steep shorelines but may develop over time on more exposed, less favourable shorelines because they start to modify the environment to suit their own success (a 'transformer' species^{ix}).

Lagarosiphon spreads via fragments that must contain an intact shoot tip or a bud to be viable^x. Fragments as small as a fingertip have proved viable as long as they included a bud^{xi}. A new infestation at a new site can occur via the transport of just one viable fragment.

Small vegetative propagules can be easily transported by human lake users and potentially survive out of water for hours to days^{xii}. Although waterfowl have been suggested to spread weed, there is a lack of evidence they are a vector for lagarosiphon between catchments. In contrast, human activities are the major factor in the spread of lagarosiphon^{xiii} between catchments and lagarosiphon distribution in lakes has been significantly associated with recreational activities. Accidental human transfer is known to occur between waterbodies via contaminated boating or fishing gear, and also through the cultivation and subsequent release of plants.

Lagarosiphon is recognised as invasive in other countries^{xiv} as well as New Zealand.

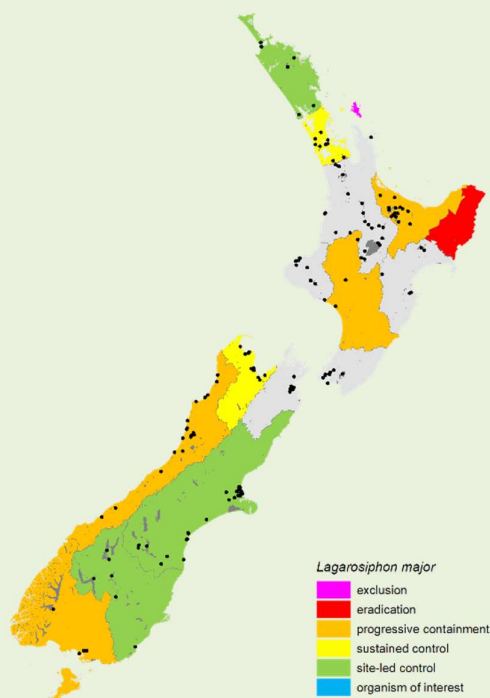
In the Otago Region, lagarosiphon is currently present in Lake Wānaka, Bullock Creek, Albert Town stormwater ponds, the Clutha River, Lake Dunstan and downstream. The weed is also present in the upper Kawarau River and is the focus of eradication in Lake Whakatipu. An outlier record is known from Puerua River (Port Molyneux). Lagarosiphon is also known from Canterbury, West Coast and Southland Regions. However, there remain numerous lakes in the Otago Region (and adjacent regions) that have not been invaded by lagarosiphon.

Lagarosiphon distribution in New Zealand

Lagarosiphon distribution in the South Island (black dots) remains restricted and a large number of waterbodies have not yet been invaded. The majority of regional councils in the South Island are managing lagarosiphon (see legend for pest management 'intermediate outcome').

Lagarosiphon is widely naturalised in the North Island (black dots) and is not managed in several regions.

Map reproduced from *Freshwater Invasive Species of New Zealand*^{xv}



2.2 Lagarosiphon impacts

2.2.1 Ecological impacts

Lagarosiphon forms tall (up to 5 m), dense weed beds. When lagarosiphon invades waterbodies, it crowds out other plants and can form surface-reaching weed beds. These dense mono-culture infestations replace native vegetation communities^{xxvi}. Invasive weed beds contrast with native vegetation communities that are usually shorter and have more open growth, allowing many, diverse species to inhabit these areas (e.g., freshwater mussels known as kākahi, and freshwater crayfish known as kōura). Moreover, the native vegetation seed bank (source for multiple plant species and genetic diversity) is slowly lost from lagarosiphon invaded sites due to seed aging and burial without replenishment^{xvii}.

Dense lagarosiphon beds reduce water mixing. Lagarosiphon weed beds were found to modify water chemistry in potentially undesirable ways according to some international research^{xviii,xix}. The impact of these differences on aquatic insects is not well understood but may include reduced diversity and number^{xx} and changes in insect composition^{xxi}. It is also thought that lagarosiphon may reduce fish access to macroinvertebrate food^{xxii} and exclude kākahi^{xxiii}.

Lagarosiphon is known as a ‘transformer’ species^{xxiv} and can modify substrates and wave action that then enhances weed bed formation.

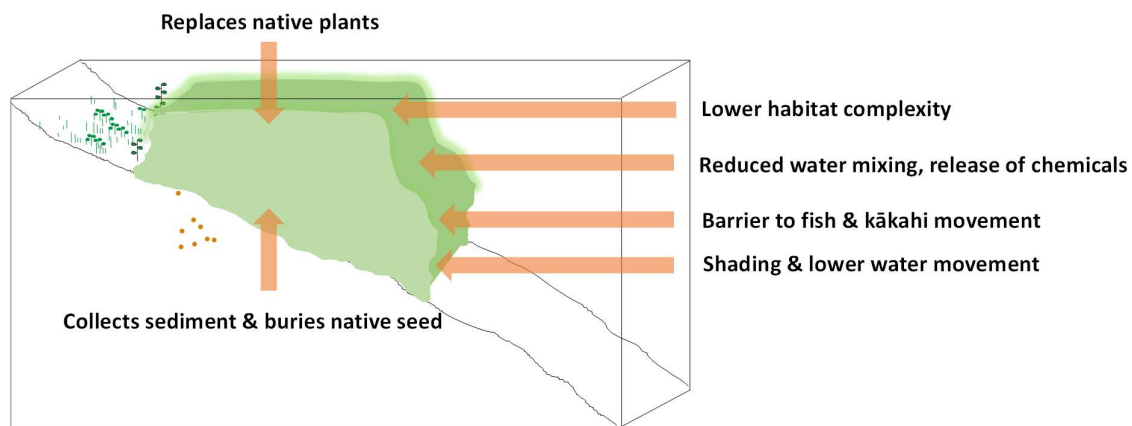


Diagram representing the ecological impacts by invasive aquatic weed beds (green)

2.2.2 Recreation, utility and economic impacts

Large, dense weed beds impact on boating activities and water-based recreation^{xxv}. Lagarosiphon, like other invasive weed beds, has been linked to drownings^{xxvi} and to ‘swimmers itch’^{xxvii}. Shoreline strands of weed beds cause odour and aesthetics issues^{xxviii}. Significant loss of hydrogeneration potential is known from the impact on power stations of surface-reaching growths of invasive submerged weeds within hydro-lakes^{xxix} and has required significant investment for weed deflection booms and high-capacity screen cleaners at stations and their ongoing operation^{xxx}. Lagarosiphon is known to contribute to inland flooding due to obstruction of drainage in channels^{xxxi}. The presence of canopy-forming weed has elsewhere been shown to impact on lakefront property values^{xxxii}.

2.3 Values at risk – Lake Wānaka

The lake is identified as an outstanding water body under the proposed Land and Water Regional Plan^{xxxiii}, requiring ORC to protect its important values. Lake Wānaka is recommended as ecologically outstanding, the proposed plan citing intact plant communities extending from the water's edge to depths of 40-50 m deep, that include a number of charophyte species and bryophyte communities with high diversity. Impacts on these ecological values are to be expected if lagarosiphon expands.

The lake is also considered to have outstanding natural character including highly coherent and memorable landscape features and very good (but declining) water quality. Widespread development of lagarosiphon would be 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^{xxxiv}.

Under the proposed Land and Water Regional Plan, Lake Wānaka is considered outstanding for a wide range of recreational uses, including being nationally significant for angling. Large beds of canopy-forming weeds are associated with depressed quantity and quality of boating, swimming and nearshore recreation^{xxxv}. Entanglement and drownings have been linked to invasive weed beds^{xxxvi}, while dense mats of weed provide good habitat for the snail hosts of parasites that cause 'swimmer's (duck) itch'^{xxxvii}, which has been recorded at Lake Wānaka. Direct lagarosiphon impacts on the recreational fishery of Lake Wānaka are uncertain but are likely mediated through physical exclusion of fish from areas of large, dense beds.

Relationship with wai Māori is recognised in the Ngāi Tahu Claims Settlement Act 1998 with statutory acknowledgement of Ngāi Tahu's cultural, spiritual, historic, and traditional association to Lake Wānaka.

Focus on ORC Inland Deep Lakes Management

In 2023, ORC signalled the establishment of an Otago Deep Lakes Management Working Group and Otago Inland Deep Lakes Technical Advisory Group^{xxxviii} to prioritise the care and evidence-based management of iconic waterbodies, Lakes Whakatipu, Wānaka and Hāwea.

The development of the Land and Water Regional Plan will have specific provisions for the Upper Lakes rohe. ORC have also signalled increased monitoring of freshwater health and a move toward an Otago Lakes Strategic Plan^{xxxix}.

2.3 Lagarosiphon and legislation, policies and plans

In Aotearoa New Zealand, lagarosiphon is designated an 'Unwanted Organism'^{xl} and banned from sale and distribution^{xli}. This ban is to prevent deliberate human spread. The introduction of any new species to freshwaters is prevented unless official permission is granted^{xlii}.

Because the South Island is a Controlled Area for the invasive freshwater algae didymo (also known as rock snot), there is a legal requirement to clean all gear used in the water before going from one South Island waterway to another waterway^{xliii}. This requirement can be met by following guidance on Check, Clean, Dry methods outlined by MPI.

Otago Region Biosecurity plans

Lagarosiphon is included under the Otago Regional Pest Management Plan (RPMP) 2019-2029^{xliv} under a 'Site-led programme'. Under this plan ORC *'supports the management of lagarosiphon within Lake Wānaka, and the Kawarau River, Lake Dunstan and to preclude the re-establishment of lagarosiphon in Lake Whakatipu'*. This RPMP aligns with stated management aims of LINZ; preventing lagarosiphon establishment in Whakatipu, progressive containment in Lake Wānaka and the Kawarau River, and sustained control at Lake Dunstan. The Plan also seeks to 'prevent the establishment of lagarosiphon in lakes, rivers and tributaries where it is not already present'.



Lake Wānaka Preservation Act (1973)

This Act^{xlv} makes provision for the protection of the natural state of the lake its water quality and for the appointment of the Guardians of Lake Wānaka^{xlvi} to advise the Minister of Conservation over issues such as affecting the preservation of the lake level and shoreline in their natural states.

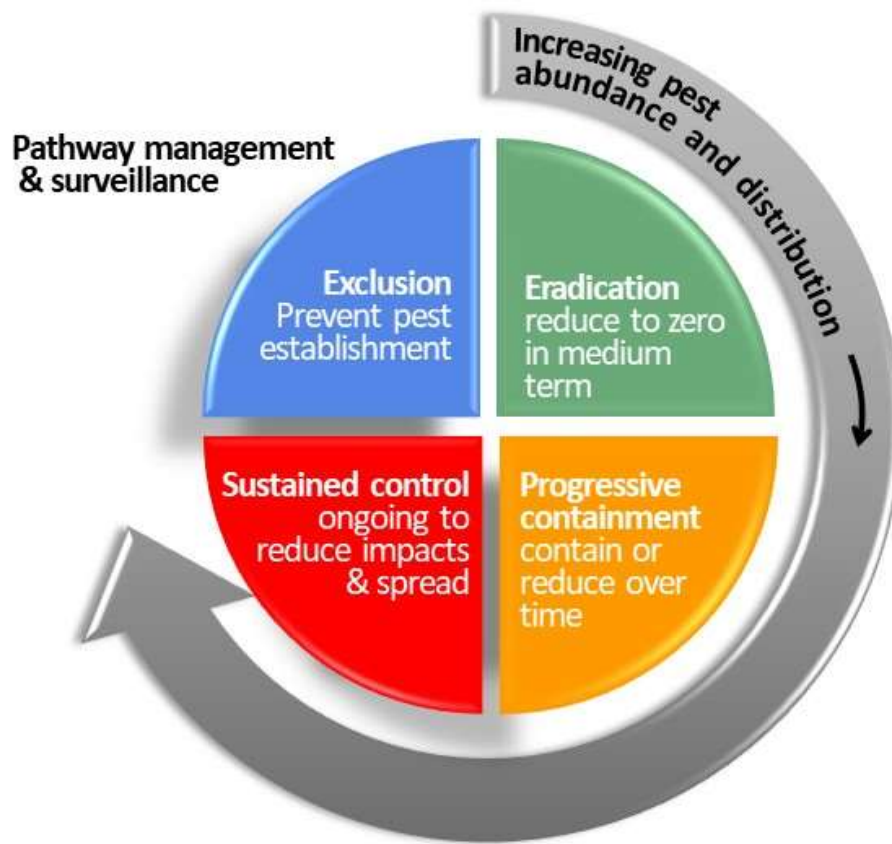
2.4 Lagarosiphon management overview in Otago Region

The management aims for lagarosiphon at sites across the Otago Region follow the intermediate outcome definitions in the National Policy Direction for Pest Management^{xlvii}. Overall, the response for lagarosiphon is a Site-led Pest Programme in the Otago Regional Pest Management Plan (RPMP) 2019-2029^{xlviii} that seeks to protect values.

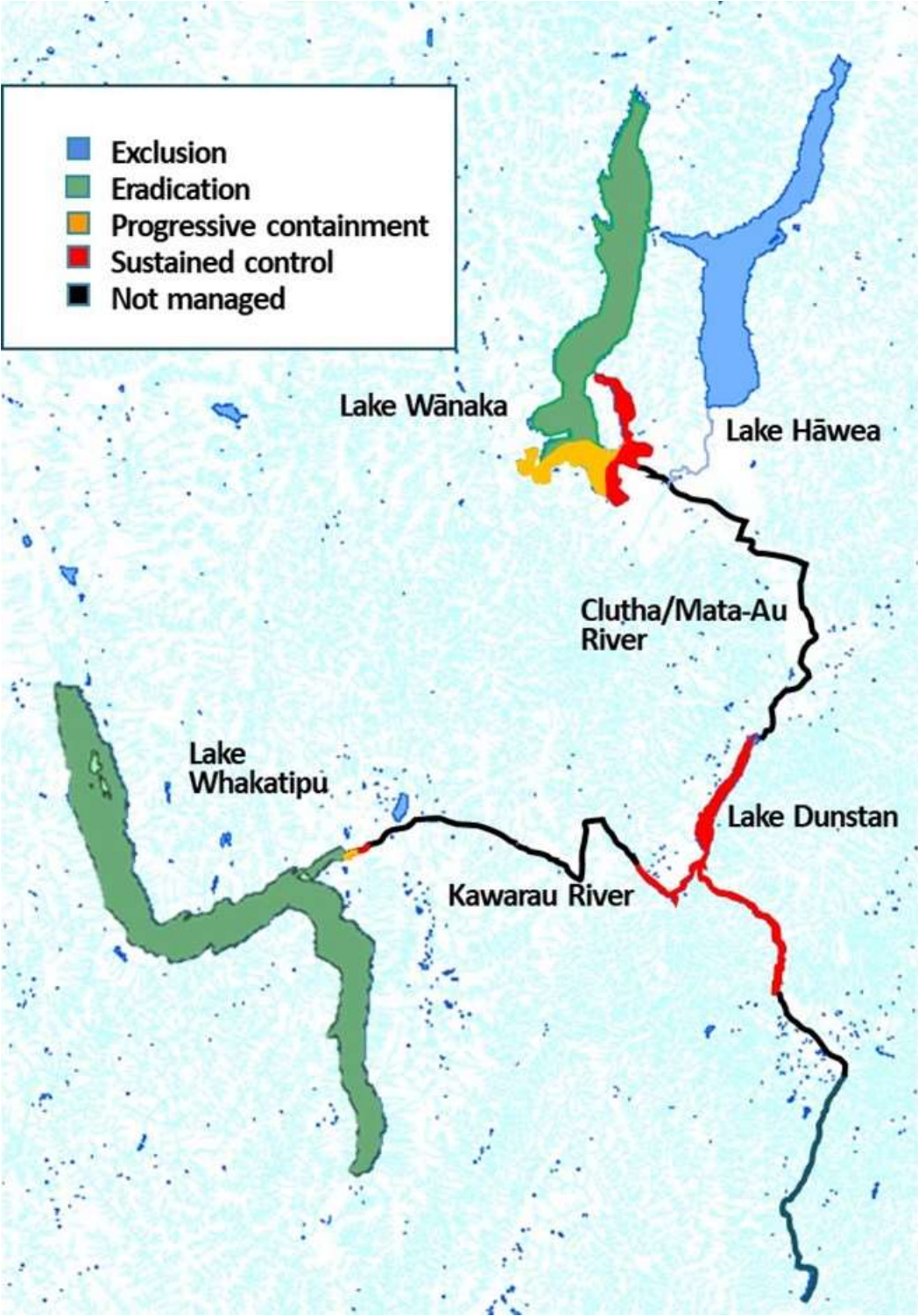
The ORC is the lead agency responsible for the prevention of lagarosiphon in currently un-infested waterbodies through managing pathways by which the weed is introduced and by regular surveillance at high-risk introduction sites. Additional species of submerged aquatic weed, egeria (*Egeria densa*) and hornwort (*Ceratophyllum demersum*) are managed as *Exclusion* species under the RPMP.

LINZ is the lead agency responsible for controlling lagarosiphon at key Otago waterbodies. Lake Wānaka in the upper Clutha/Mata-Au catchment has the overarching aim of *Progressive containment*, with a strategy of *Eradication* in the northern two-thirds of the lake, *Progressive containment* in the south-west and *Sustained control* currently in the remainder of the lake. Lake Whakatipu at the head of the Kawarau catchment has the aim of *Eradication*. The aim for the upper Kawarau River flowing out of the lake is *Progressive containment* in a downstream direction. Receiving source lagarosiphon via both upper Clutha/Mata-Au and Kawarau catchment drainage is Lake Dunstan. Here, the aim is *Sustained control*, particularly at amenity sites to prevent the transfer of lagarosiphon to other currently unimpacted sites.

Four intermediate outcomes for pests



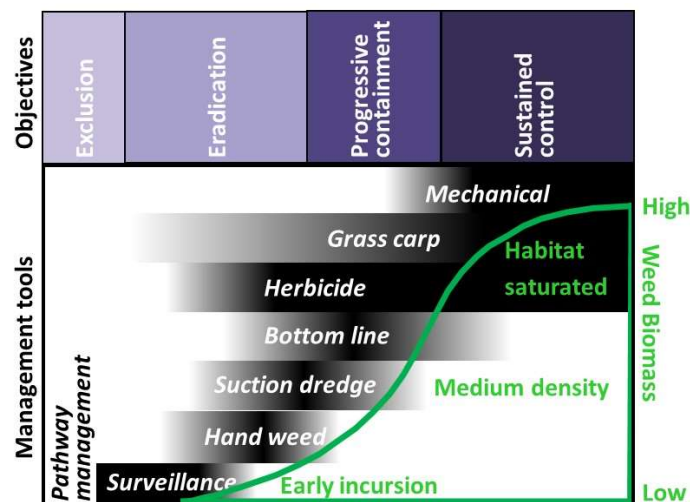
Map of LINZ management aims for lagarosiphon



3 Weed management approaches and tools

The choice of tool for the control of lagarosiphon depends partly on the objective sought, the biomass of the weed present, and characteristics of the site where control is enacted.

The control tools are not exclusive. Tools may be used together (e.g., surveillance and hand weed) or in sequence (e.g., herbicide followed by suction dredge or hessian). Not all tools are used at all sites and grass carp as a control tool is not used in any of LINZ key sites because the fish cannot be contained in target areas.



Aquatic weed management tools mapped to weed biomass and the objective (intermediate outcome) sought at sites.

3.1 Pathway management in Otago Region

ORC take a lead for the management of pathways by which lagarosiphon (or other aquatic pests) may be distributed and spread in the wider Otago region. This includes checking compliance with regulations (e.g., pet shop and nursery inspections), surveying potentially infested properties (e.g., privately owned ponds) and undertaking inspections and surveillance of non-LINZ managed sites described under the annual ORC Lagarosiphon Management Plans (ponds, lakes and rivers)^{xlix}. ORC, with MPI funding and guidance, undertake annual advocacy for lake users following the MPI Check, Clean, Dryⁱ messaging.

Control works for lagarosiphon undertaken by the LINZ Aquatic Weed Control Programme contribute to pathway management by removing lagarosiphon weed beds adjacent to amenity areas (e.g., boat ramps, jetties, ski lakes, swimming pontoons) at key waterbodies in Otago Region (Lakes Wānaka, Dunstan, Whakatipu and the Kawarau River). This reduces the risk of lake users transferring lagarosiphon to other waterways in New Zealand.

Additional potential steps for pathway management include the provision of washdown facilities for vessels entering at risk lakes at amenity sites^{li} or treatments for contaminated boats^{lii}. This includes the use of portable wash-down units used at events and high use areas for the dual purpose of decontamination and reinforcing Check, Clean, Dry messaging^{liii}. Weed cordons, a netted containment area, can be used at boat ramps designed to capture weed fragments introduced on trailers or vessels arriving from infested sites^{liv}.

3.2 Surveillance

Detection and delimitation of submerged weeds is a key initial management step, particularly for initial incursions. Currently, best practice involves in-water observation of the lakebed within key lagarosiphon habitat (0-6.5 m depths) by divers (snorkel or scuba) or submerged cameras viewed in real-time. Geospatial records for incursions or weed boundaries is essential for documenting incursion size or plant distribution patterns.

3.3 Hand weeding

Snorkel or scuba divers can hand remove individual plants where they are not too large or dense for this method to be feasible^{lv}. All green material, including the 'root crown' at the very base of the plant, must be removed and contained, such as within a spring-loaded 'catchbag'. Non-green roots within the sediment can be left, but it is important to remove any stem fragments that may have been dislodged during hand weeding.

Hand weeding has limited effectiveness where large numbers of weed fragments can reinvade from upstream or adjacent weed beds. It also requires skilled divers that are experienced in weed removal. It can be difficult for divers to cover wide shallow littoral zones systematically to remove all plants or to excavate root crowns in hard sandy substrates.



3.4 Hessian bottom lining

Jute hessian is deployed as a 'bottom lining' or 'benthic barrier' to shade and smother lagarosiphon plants that are too dense to hand weed efficiently. The hessian covered weed bed remains green and viable for some time, but generally dies within 4 to 5 months^{lvi}.



Advantages to using hessian include that it is biodegradable, breaking down after c. 10 months^{lvii}, and the open weave allows native plants to grow through the material as germling plants, or from stems that are narrower than lagarosiphon^{lviii}. The hessian also 'encapsulates' the weed bed so that fewer fragments escape from covered areas to establish new plants elsewhere.

Disadvantages include time and labour costs for installing hessian. It cannot be laid over very uneven or rocky slopes or where waves and currents dislodge the material. Boat propellers or fishing lures can also tear the lining. Importantly, hessian bottom lining should only be used for systematic weed bed clearance along shorelines or for outlier weed beds that cannot be effectively removed by hand weeding. Hessian bottom lining will not be effective if used in areas where large numbers of lagarosiphon fragments drift back into treated areas and re-establish. Follow-up hand weeding is generally required at regular intervals (3-6 months) after hessian bottom lining to remove remaining lagarosiphon plants.

Deploying hessian

Hessian floats when it is dry and neutrally buoyant when soaked. Divers lay out the material and peg it in place using metal 'staples'. Hessian must be laid flat, as sediment fouling is required over the surface to completely shade and smother weed beds. Therefore, the weight of the hessian (i.e., weave density), and tensioning of the material can be critical and special 'roller' systems to deploy the bottom lining have been developed by contractors employed within the LINZ lagarosiphon management programme. Hessian can be challenging to deploy over tall, bulky weed beds and may require the use of herbicide to reduce biomass before laying the bottom lining.



3.5 Suction dredging

Weed bed removal by suction dredging involves a diver-directed suction tube, with plants pulled or cut from bed of the waterbody, fed into the tube and removed to a floating barge via a venturi suction pump. Plants can be collected in a fine mesh collection bag onboard a barge^{lix}, or potentially mulched to ensure the majority of fragments are no longer viable and released back to the water to remove the need to off-load and dispose of bulky weed. The method has the advantage of removing the lagarosiphon root crown. Suction dredging has been used to eradicate weed^{lx} and for restoration of native plant diversity^{lxi}.



Disadvantages include high labour cost of suction dredging, making it feasible only for moderate biomass beds in limited areas. Specialist equipment, skilled operators and divers are needed to effectively implement suction dredging. This control method requires good underwater visibility and is slowed by hard-packed sediments and underwater obstacles^{lxii}. Targeted use of herbicides may reduce effort by decreasing weed biomass prior to suction dredging. Suction dredging can provide effective control of lagarosiphon weed beds for up to three years. However, follow-up hand weeding will be required to achieve weed eradication due to regrowth from any remaining propagules.

3.6 Diquat herbicide

Diquat dibromide is one of two aquatic herbicides currently registered by the Environmental Protection Authority (NZEPA) for use for control of submerged aquatic weeds in New Zealand freshwaters. It has been used for aquatic weed control in this county for over 60 years. Diquat acts by damaging the green tissue of susceptible plants^{lxiii} leading to a reduction in the height and density of weed beds but can also temporarily slow the growth of weeds. However, diquat does not usually entirely kill lagarosiphon plants and regrowth usually occurs in time.

The diquat herbicide label (legal instructions for use¹) in New Zealand stipulates a rate of 30 litres per ha of water surface, regardless of water depth. Water volumes in areas deeper than >0.3 m depth rapidly dilute diquat to <1 mg per litre, the recommended concentration for weed control. However, lower concentrations can reduce weed biomass if in contact with the plant tissues for sufficient time^{lxiv}.

¹ Legal document providing important information about a herbicide, its appropriate use, and the precautions needed to protect environmental quality.



Tall growing lagarosiphon weed beds (left) can be substantially reduced by the application of diquat herbicide (center and right).

While lagarosiphon and other major aquatic weeds are susceptible to diquat, native plants are less susceptible or are not affected at the rates used for weed control^{lxv}. Further, native submerged plant communities can re-establish from seedbanks in the sediment, unlike lagarosiphon which does not form seed in New Zealand.

Diquat can be applied by aircraft, boats using surface and submerged booms or subsurface injection via trailing hoses, by gun and hose, or by diver injection into weed beds. These application methods depend on the size of the area to be treated and suitability of the site. A gelling agent may be added to sink the applied herbicide mixture to the depth where weed beds are located. Diquat is rapidly deactivated by locking onto sediment particles in the water or on plants and the lake bottom^{lxvi}. Therefore, this herbicide should not be used when water or target weeds are dirty.

The advantage of diquat is that large areas can be treated in a short period of time, control outcomes are relatively rapid, can be achieved at scale, and generally have a lower cost than other available weed control methods.

Diquat and lake users

The diquat herbicide label (legal instructions for use) in New Zealand stipulates a bathing/swimming restriction of 24 hrs for treated waters. While this precautionary approach persists in this country, scientific risk assessments^{lxvii} have seen the removal of any swimming restriction for diquat treated waterways in the United States since 2002.

A 24-hour restriction on use of water for drinking and stock water applies in New Zealand. There are no restrictions on recreational fishing.

There is a 10 day 'withholding period' before diquat treated water should be used for overhead irrigation, but this can be reduced to 24 hrs if the treated water is flowing.

Diquat and the environment

Diquat must be used in keeping with the Label (legal instructions for use). Diquat is rapidly absorbed by weeds and tightly binds to suspended particles and bottom sediments. This means diquat is generally only detectable in the water column for a short time-frame (minutes to hours rather than days)^{lxviii}. Diquat has negligible risk to other aquatic biota at the concentrations applied to the aquatic environment for weed control^{lxix}. Sediment-bound diquat has no residual toxicity, is not biologically active and is degraded slowly by microbial organisms. No accumulation of diquat has been detected in sediment analysed from freshwater sites that have been regularly treated^{lxx, lxxi}.



Lagarosiphon reinvading amongst native submerged vegetation at Roys Bay boat ramp, Lake Wānaka after diquat treatment.

3.7 Mechanical

Machines to mechanically cut and harvest lake weed generally comprise a boat-mounted sickle bar that cuts the weed below the water surface. The weed bulk may be collected on a conveyor belt as the machine moves forward and disposed on shore or left in-lake. Different configurations of machinery determine depth of cutting (usually 2 m, but up to 5 m) and the width of the cut swath^{lxxii}.

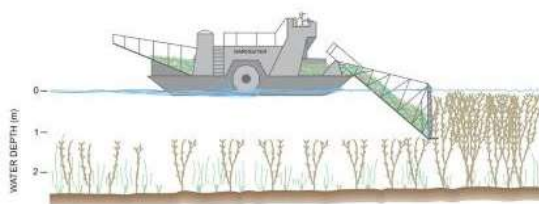


Diagram of harvester removing the weed bed canopy, modified from Wisconsin Department of Natural Resources and SEWRPC².

² Wisconsin Department of Natural Resources and SEWRPC (https://apps.dnr.wi.gov/doclink/lakes_grants_reports/SPL-023-02.pdf)

Advantages to mechanical control include an immediate reduction in weed nuisance at a site.

Disadvantages include capital outlay costs and ongoing operator costs, the need for off-load sites with truck access^{lxxiii} (e.g., boat ramps), slow speed and limited load size impacts on cutting time^{lxxiv} and impacts on water quality^{lxxv} and biota^{lxxvi}. Weed beds can also re-establish quickly (50-100 days^{lxxvii}) from remnant lagarosiphon stems and root crowns that are not removed. Harvesting should not be used in/near areas where progressive containment or eradication are sought, due to the potential for high fragment loads to be generated. Machinery should be dedicated to one waterbody or strict biosecurity decontamination protocols followed to prevent unintentional spread of biota.

3.8 Grass carp

Grass carp (*Ctenopharyngodon idella* Val) are herbivorous fish introduced to New Zealand from Asia for weed control. Grass carp are highly likely to impact on native vegetation values in lakes because grazing is not limited to the target weed^{lxxviii}. Moreover, vegetation control is only achieved where a sufficient stocking density of fish can be retained^{lxxix}, which would not be feasible in large lakes with substantial river outflows and multiple tributaries. This makes them an unsuitable control tool for the key waterbody sites that are managed under the LINZ programme.

3.9 New management technologies

Future advances in management and control tools are likely that could radically change the effectiveness of management and potentially costs, with the result that greater management progress can be made. One example is the adoption since 2016 of hessian bottom lining, which is now widely used within the LINZ management programme for lagarosiphon.

Automated detection of submerged invasive weeds

NIWA is currently developing a detection system for lagarosiphon that harnesses computer processing power to 'recognise' lagarosiphon from underwater imagery^{lxxx}. The concept is that a trained computer module can view imagery in the field and detect instances of lagarosiphon shoots, with the simultaneous recording of GPS location and confirmatory image that is available for viewing in near real-time. The 'detection module' would be deployed on a vessel to initially undertake surveillance instead of the need for a dive team. The dive team could then be directed to the recorded locations to enact control. Because this system would be a more cost-effective method for the detection of low occurrence it would 'free up' budget for other control activities once developed.

Endothall herbicide

Endothall dipotassium is registered for use for control of submerged aquatic weeds in New Zealand freshwaters. It is a contact herbicide that desiccates plant tissue^{lxxxi}. However, endothall is also known to have some systemic activity (transported within the plant)^{lxxxii}. Unlike diquat, endothall is not deactivated by turbid water^{lxxxiii} or dirty plant surfaces.

Disadvantages include a much longer time needed for endothall contact with target submerged plants for effective control compared to diquat, being several hours to days^{lxxxiv}. The use of endothall requires compliance with a permission from the NZEPA and a Resource Consent for all regions. Withholding periods stipulated for the use of abstracted water in New Zealand under the current NZEPA permission may be difficult to observe. *Egeria* (*Egeria densa*) is poorly controlled by use of endothall^{lxxxv}.

How can endothall be used?

The endothall product used in New Zealand is 'Aquathol K®'. Endothall is applied to water by similar means to diquat. However, under the herbicide label (2021) 'Direction for Use', a rate of 3-5 mg per litre of the active ingredient (endothall dipotassium salt) is applied to target areas at a concentration that is calculated based on *the volume of the weed bed targeted*.

This product label instruction differs from how this herbicide is used internationally. For example, the USA endothall label stipulates treatment concentrations between 2-5 mg per litre on a *water volume* basis. Therefore, in New Zealand it is difficult to achieve control of weed beds located in deep water due to dilution and dispersion of the herbicide. This currently limits use in the LINZ lagarosiphon management programme and research is needed on ways to improve herbicide contact with target weeds, such as drop nets or containment booms to retain endothall concentrations within target weed beds.

New herbicides

A range of new-generation herbicides are being used to manage submerged weeds internationally. Amongst these are herbicides that are effective at much lower concentrations than diquat or endothall. Two such herbicides that have shown efficacy against New Zealand target weeds under experimental tank conditions, with limited off-target impacts on native plants are flumioxazin^{lxvii} and florypyrauxifen-benzyl^{lxviii}. Also in use overseas is a dual formulation diquat and endothall combination (i.e., Aquastrike™). This herbicide combination has the advantage of treating combinations of weed targets with differing herbicide susceptibility with one application cost. All new aquatic herbicides must go through the registration process with the NZEPA before use against submerged weeds in New Zealand.

Herbicide placement technologies

For effective herbicide outcomes, one challenge is to deliver the herbicide to target plants within a diluting water environment. For example, currently a gel carrier is routinely added to diquat to assist placement. Other possible solutions exist including encapsulation or matrix carriers. Other methods of application include low-dose metering injections of herbicide to maintain effective contact times with weed beds. Automated metering systems have been used internationally^{lxviii} to maintain the desired herbicide concentration in linear-flow systems with fluctuating flow rates. Currently there is no regulatory provision in New Zealand for such a practice in relation to aquatic herbicides.

Classical biological control

Elsewhere, suppression of submerged weeds has been attempted by releasing insects that feed on the plants. In the USA, four insects were released, two established but none adequately controlled the submerged weed *Hydrilla verticillata*^{lxix}. A leaf-mining fly *Hydrellia lagarosiphon* has been considered as a control agent against lagarosiphon in New Zealand and Ireland^{xc}.

Suppression using classical biological control is suitable only for sustained control outcomes and would not achieve progressive containment or eradication goals within the LINZ aquatic weed management programme.

Would classical biological control have a place in LINZ aquatic weed management programme?

Some doubt exists about the usefulness of a classical biological control for submerged weeds. Firstly, although the herbivorous larvae of a widespread native moth, *Hygraula nitens*, can control a range of submerged weeds under experimental conditions^{xci}, levels of grazing damage to lagarosiphon in the key lakes is minor despite larvae being detected at Lakes Dunstan, Wānaka and Benmore. This raises questions whether a similar grazing insect will build up sufficient populations to exert significant control under natural conditions and in the presence of generalist predators, including fish.



4 Scenario of no control

If no control programme had been initiated for lagarosiphon at the key sites managed today, a very different scenario for aquatic weed status would currently exist in the iconic South Island lakes. This 'counterfactual' is supported by knowledge on lagarosiphon habitat requirements, aquatic weed invasion dynamics in these and other lake systems and by estimates of the habitat available within the management system.

Eradication economics

A recent analysis^{xcii} identified that three principles relating to intervening in invasive aquatic weed incursions were broadly considered to be logical in an economic sense and contribute to supporting intervention decision-making. These principles were:

- Eradication is more expensive than other outcomes in the short-term (i.e., sustained control or no action) but cheaper than long-term impacts.
- Eradication costs were smaller where eradication was started early, and incursion sites were smaller.
- Preventing incursions will be cheaper in the long run than eradication.

Lagarosiphon weed beds form within water depths of up to 6 m, where there is adequate light for growth, a moderate slope, suitable fine substrate as a stable rooting media, current flow rates $<1 \text{ m sec}^{-1}$ and a wave exposure $<4 \text{ km}^{\text{xciii}}$. However, lagarosiphon is also considered a ‘transformer’ species, which can change the character or condition of ecosystems. In this regard it is likely that lagarosiphon colonisation will make conditions more suited for growth of weed beds by modifying wave exposure and by the deposition of fine organic-rich sediments under weed beds over time.

4.1 Unmanaged aquatic weed invasion in Lake Wānaka

In the absence of management, extensive further shorelines of Lake Wānaka would become infested with lagarosiphon, with the likelihood of additional areas of surface reaching weed beds. The entire lake shoreline could be expected to become ‘saturated’ with weed (all available habitat colonised) within a timeframe of 5-10 years, based on weed invasions elsewhere and past performance of lagarosiphon in Lake Wānaka^{xciv}. For example, lagarosiphon quickly spread throughout the southern part of Lake Wānaka within four years of colonisation, despite weed control measures being undertaken. Spread to the northern head of Lake Wānaka would likely be mediated by boat traffic within five years. Wave modelling suggests nuisance weed beds would develop in sheltered bays and along more protected shorelines. Less favourable areas would likely see some development of lagarosiphon. The popularity of Lake Wānaka for boating would see it become a major ‘hub’ for spread to additional lakes via recreation related dispersal (e.g., contaminated boats and trailers).



5 Timeline of Lake Wānaka lagarosiphon management

Lagarosiphon records	Year	Key management events
Bullock Creek, Roys Bay	1972	Eradication goal multi-agency response
Nuisance in marina	1973	Hand weeding
	1974	Containment goal Diquat treatments started
	1975	
Ruby & Stevenson Islands	1976	NZED funding – protect future Lake Dunstan
Glendhu, Parkins & Dublin Bay, river outlet	1977	
	1978	MAF as technical advisors
	1979	Eradication goal, Lands & Survey managers
	1980	Suction dredging, bottom lining trialled
	1981	
	1982	Lagarosiphon nursery/aquarium trade prohibited
	1983	
	1984	
	1985	
	1986	
	1987	Department of Conservation begin management
	1988	Electricorp (ex NZED) funding ceased
	1989	
	1990	
	1991	DOC funding reduced 9 months of no management
	1992	
	1993	Regional Pest Management Strategy, Containment
	1994	
	1995	
	1996	
	1997	
	1998	LINZ resume management, with Opus International
	1999	
	2000	'Rototilling' trialled in Paddock Bay
	2001	Landward Management Ltd undertake amenity control
	2002	5-yr plan amenity control & preventing spread
	2003	Concerned agencies, workshop on increased infestation
	2004	MOU developed for multi-agency group
	2005	Government funding doubled, campaign against diquat
	2006	10-yr management plan, protection & containment
	2007	Otago RPMS recognises 10-yr plan
	2008	Designated zones for eradication, buffer & target control
	2009	LINZ contract Boffa Miskell
	2010	LINZ containment line shifted south
	2011	Site Prioritisation Model
	2012	
	2013	LINZ containment line shifts south
	2014	
	2015	Private funding contribution
	2016	10 year management plan, progressive containment
	2017	Progressive containment in Western Target Control Zone
	2018	Endothall use at Albert Town Lagoons
	2019	Regional Pest Management Plan, additional 7.5M funding
	2020	Regional Lakeweed Forum held
	2021	Terms of Reference drafted for stakeholder group
	2022	
	2023	



Hand weeding c. 1978



Weed surveillance 2005



Weed beds Paddock Bay 2005

Suction dredging Mou Waho & Mou Tapu
Suction dredging West Wanaka



Paddock Bay 2014

Albert Town Lagoons

6 Control strategies in Lake Wānaka

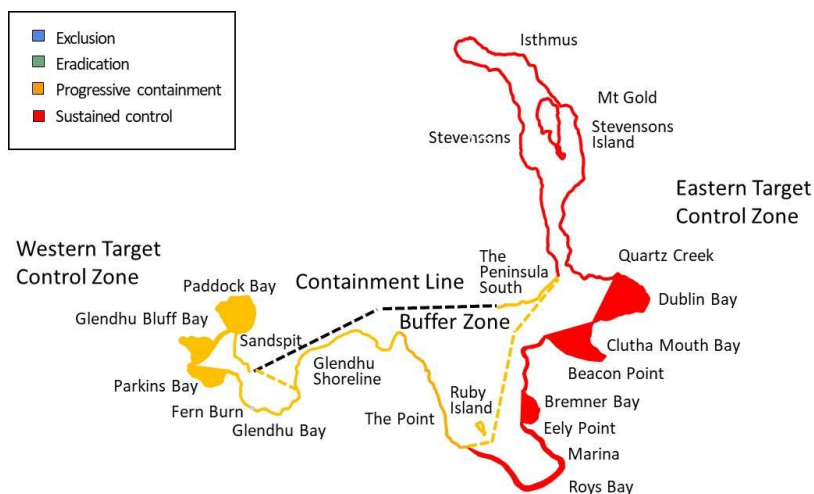
Management Zones and shoreline units

For lagarosiphon management, Lake Wānaka is designated into three Zones and component shoreline units.

The Eradication Zone comprises 25 shoreline units in the northern lake.

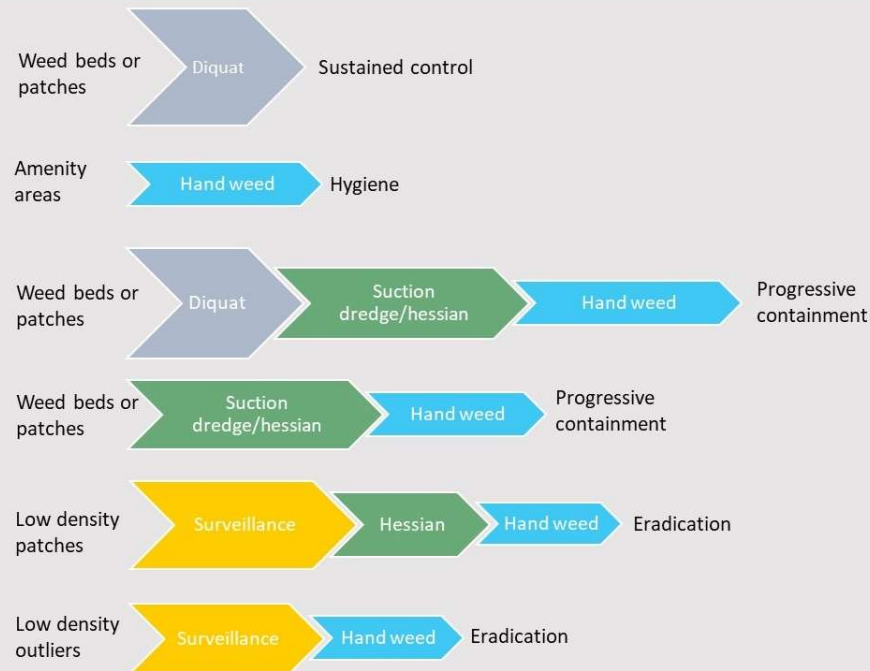
Target Control Zones in the east and west of the southern lake. The western Target Control Zone of six shoreline units has been the focus of progressive containment, while sustained control has been the outcome sought in the eastern Target Control Zone.

A Buffer Zone, comprising four shoreline units, lies between the Eradication and Target Control Zones.



Tactical, site-specific response

In order to achieve the intermediate outcomes at Lake Wānaka, tactical sequences of control tools have been employed at specific sites, depending on the weed biomass and site constraints.



6.1 Current status and control

6.1.1 Eradication Zone

The northern lake receives fragments conveyed up the lake by currents and/or boats. Fragments colonise suitable habitat, mostly along the western shoreline and islands closest to the containment line. The outcome sought in this zone is the eradication of every established plant or fragment. This is achieved via surveillance and hand weeding, with hessian bottom lining employed as 'insurance' where the possibility exists of fragments remaining hidden in the substrate or background vegetation.

Wider Otago surveillance for lagarosiphon

In recent years, ORC have undertaken surveillance of freshwater pests including lagarosiphon, limited to those waterbodies that are not currently being controlled by LINZ. ORC is implementing a freshwater biosecurity surveillance and monitoring plan (including lagarosiphon monitoring) that identifies waterbodies prioritised for surveillance and the associated frequency.

In 2023/24, lagarosiphon monitoring and surveillance was undertaken in 54 water bodies region-wide, inspected by ORC staff. Reprioritisation of surveillance sites may occur annually.

Surveillance in Lake Wānaka

Initially, ORC funded all of the monitoring for lagarosiphon in the region, but not the control works, as stated in the 1996 Pest Plant Management Strategy for the Otago Region^{xcv}. The 2005 Lagarosiphon Management Plan for Lake Wānaka^{xcvi}, stated ORC was responsible for monitoring the whole of Lake Wānaka on a two-yearly cycle to detect new outbreaks of lagarosiphon. Later, the need for synchronisation and communication between the ORC surveillance team and LINZ contractors undertaking lagarosiphon removal as recognised as vital^{xcvii}. Subsequently, ORC contributed funding for LINZ to undertake all surveillance in Lake Wānaka for efficiency. That funding was later withdrawn when ORC funding into the LINZ programme was refocused on sustained control at Lake Dunstan. LINZ currently undertake all lagarosiphon surveillance at Lake Wānaka.

LINZ strategy for lagarosiphon surveillance within the Eradication Zone of Lake Wānaka focuses on risk, with the interval for surveillance being 6 months for high-risk sites (as shoreline units) 12 months for moderate-risk sites and 18 months for low-risk sites. The interval changes in response to changed risk based on the history of detections. LINZ contractors cover all the shoreline unit at the prescribed interval using divers. In some circumstances, underwater cameras may be viewed for detecting plants. Lagarosiphon biomass removed by divers is greatest from the Bishops Bay shoreline unit that is closest to existing lagarosiphon weed beds.



6.1.2 Buffer Zone

Shorelines in this zone lie between the Eradication Zone and the eastern and western Target Control Zones. The outcome sought is progressive containment to reduce weed biomass to a level that will minimise weed fragment export into the Eradication Zone.

Progressive containment is primarily achieved by hand-weeding in this Zone. However, a remaining c. 800 m section of the Glendhu Shoreline management unit requires weed beds to be initially controlled by other means (herbicide, hessian/suction dredging). This section is contiguous with the Glendhu Bay management unit in the western Target Control Zone and is of relatively low risk for fragment load generation.

6.1.3 Western Target Control Zone

The wider Glendhu Bay area is a major recreational hub and has been the focus of progressive containment of lagarosiphon since 2016. Significant progress has been made in clearing lagarosiphon weed beds.

Combinations of diquat, hessian, suction dredging and hand weeding have achieved the removal of most of the weed beds in this Target Control Zone. Currently in 2024, less than 1 km of shoreline is estimated as remaining to be cleared of weed beds. However, ongoing maintenance work is vital to the maintain the controlled areas clear of lagarosiphon reinvasion. When weed bed clearance is completed, anticipated by 2025, this area can be added to the Buffer or Eradication zone.

6.1.4 Eastern Target Control Zone

Significant lagarosiphon weed beds are distributed around much of the shoreline units of Roys Bay, Dublin Bay and Stevensons Arm. Opportunities for strategic sustained control using diquat have been sought in this area. This approach has seen intermittent treatment of areas adjacent to amenity areas and facilities, to aid in 'hygiene' outcomes sought (see below), or to improve amenity values, with the benefit of lower weed contact and potential transfer by lake users.

Wanaka Marina within this area is managed outside of the LINZ control programme, according to responsibilities under Resource Consent. Control is achieved by diquat treatments about once a year.



6.1.5 Hygiene at amenity areas

Six key amenity areas at Lake Wānaka are controlled for lagarosiphon within the LINZ programme to reduce the risk of transfer to other waterbodies. The aim is to reduce the risk of lake users contacting weed on vessels, trailers or equipment by reducing the height and density of weed around ramps, jetties and at frequently accessed shorelines. This is achieved locally by hand weeding, although diquat applications have assisted in this maintenance at some amenity sites.

6.2 Risks to progressive containment of lagarosiphon in Lake Wānaka

There are a number of risks to the management programme aim of progressive containment of lagarosiphon in Lake Wānaka.

The greatest risk is from *inadequate funding* to implement the required control work. Current resourcing needs to maintain the gains in eradication and weed bed removal achieved in previous years, but also move ahead the containment front in the western Target Control Zone (Glendhu Bay) if the goal of progressive control is to be progressed. Presently there is no contingency funding to address additional risks should they eventuate.

Introductions of *additional aquatic pests* (e.g., hornwort or egeria) represent risks if additional responses need to be undertaken that dilutes resourcing for lagarosiphon. A number of aquatic pests share the same pathways and vectors as lagarosiphon so some activities described within this ten-year plan will contribute to reducing these additional pest risks.

Impacts on lagarosiphon management from *climatic, weather and lake conditions* have been realised previously. For instance, larger than usual loads of lagarosiphon fragments reaching the northern Eradication Zone have been associated with southerly winds and/or very low lake levels. Use of some control tools require lake and weed bed conditions that are influenced by short-term weather conditions (e.g., plant condition suitable for diquat application).

Regulatory constraints have the potential to impact the control tools and activities in the lagarosiphon management programme. For instance, the use of endothall herbicide at Lake Wānaka is restricted under the current label (directions for use) and NZEPA permissions that apply in this country. Future emerging regulatory requirements have the potential to delay or prevent adequate biosecurity responses.

Changing 'riskscapes' in the local environment may not be adequately planned for. For example, changing human pressures, in-water or lakeshore developments and changing public access points shift risks and required management responses.

7 LINZ annual operational planning

The annual operational planning for weed control works within the LINZ Aquatic Weed Management programme starts with the budget allocation.

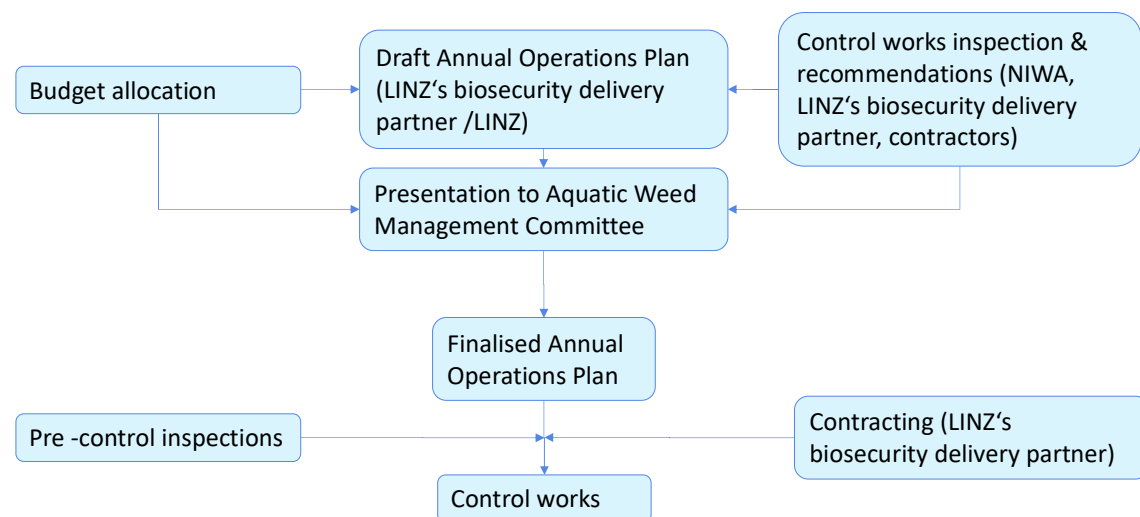
Results from inspections of the control works in the previous year, operational aspects and information from contractors feed into a draft Annual Operations Plan. Recommendations for operational improvements and priorities are also incorporated. The plan should identify the most cost-effective method at each site to achieve site specific priorities contributing to the overall objective (Intermediate Outcome) and indicate the likely timing of control works.

The draft Annual Operational Plan is presented to the Committee for stakeholder input and approval and the finalised plan circulated.

LINZ's biosecurity delivery partner engages contractors that meet LINZ programme requirements (e.g., qualifications, experience, health and safety requirements). Control works are then scheduled. One of the initial tasks is to inspect the sites for weed and site conditions that may determine the timing or control methods used, particularly in assessing that conditions are suitable for herbicide operations.

Opportunities for feedback on the Annual Operational Plan should occur during the year, based on progress, shifting priorities, funding opportunities and any issues that arise.

This annual planning process enables the weed management programme to be adaptive, responding to progress as it is made, realigning subsequent priorities, and addressing any arising issues. Progress also needs to be compared to the agreed goals, objectives and milestones of this plan.



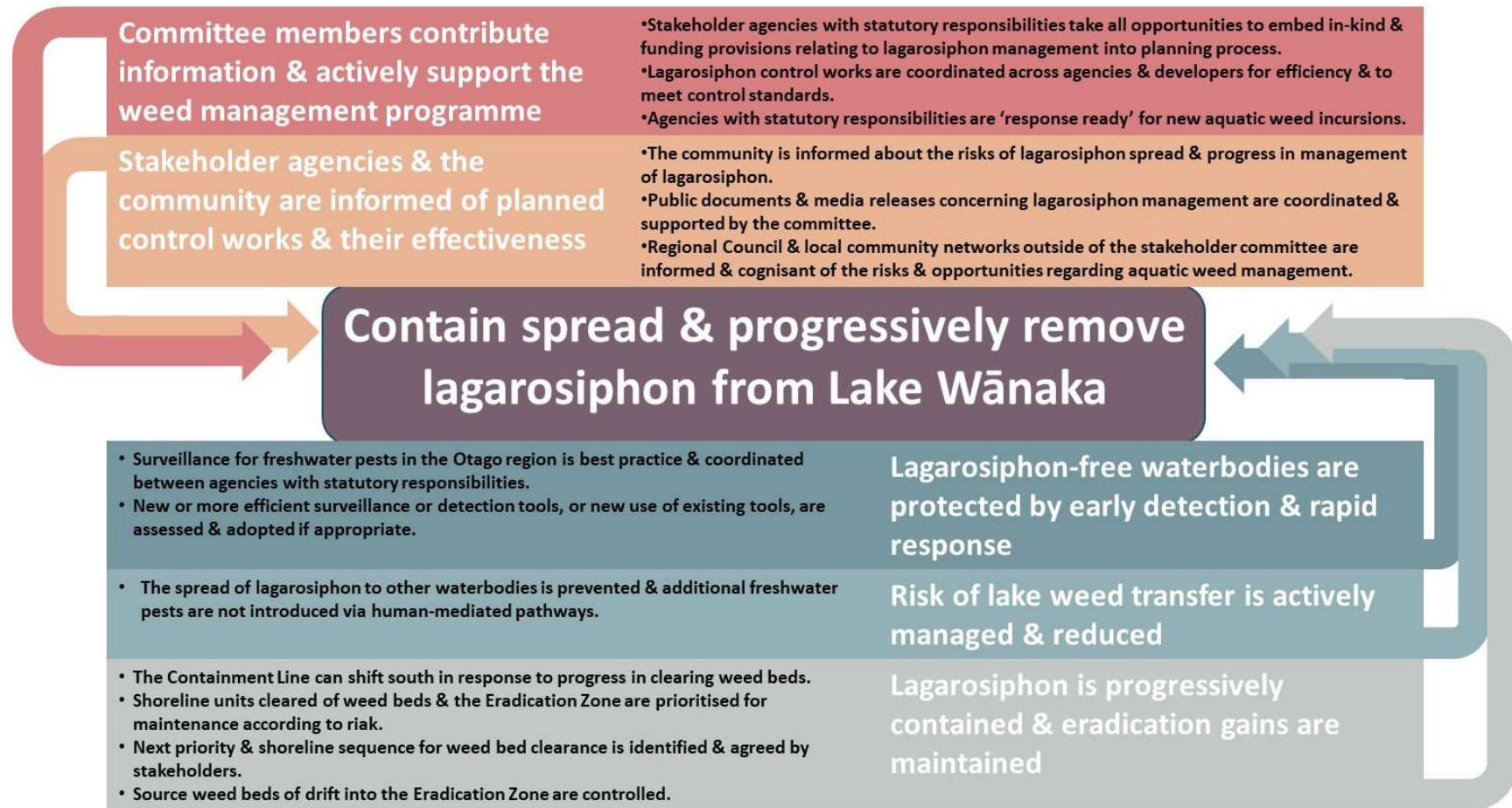
Main steps in the annual operational planning cycle

8 Communications plan

The Terms of Reference (TOR) for the Aquatic Weed Management Committee states that all media approaches with respect to the Committee and the lagarosiphon management plan shall be referred to LINZ as the chair. LINZ intend that a higher-level comms strategy for the control works programme would include the approach of being:

- Collaborative. Agencies involved in management of the lake weed will work together to align messaging and community engagement activities.
- Results focused. We aim to engage the community in our collective cultural, social and biodiversity goals associated with the control and removal of lagarosiphon.
- Proactive. We will engage early and ensure the local community is aware of biosecurity risks, operations, challenges and any impacts on cultural or recreation activities.

9 Lake Wānaka vision, goals, objective and milestones



Schematic of the vision (centre), goals (white text) and objectives (black text) relating to the Lake Wānaka Lagarosiphon Plan: 2025 -2035.

Vision: ***Contain spread and progressively remove lagarosiphon from Lake Wānaka***

Goals	Objectives	Milestones
Goal One Committee members contribute information and actively support the weed management programme	A. Stakeholder agencies with statutory responsibilities take all opportunities to embed in-kind and funding provisions relating to lagarosiphon management into planning process.	1. Regional and district councils report to the committee on opportunities and timing for funding provision or agreements on lagarosiphon control for multi-year terms aligned with planning processes. <i>By August 2025</i>
		2. Stakeholder agencies receiving applications for in-lake/river development or changes to lake amenities have a system in place to alert members of the committee and incorporate feedback into Consent Conditions. <i>By May 2025</i>
	B. Lagarosiphon control works are co-ordinated across agencies and developers for efficiency and to meet control standards.	3. Developers ³ at lagarosiphon infested sites engage with LINZ with regards to the funding of control works in defined areas within the LINZ programme area. <i>Ongoing</i>
	C. Agencies with statutory responsibilities are 'response ready' for new aquatic weed incursions.	4. Stakeholders contribute to an aquatic pest incursion scenario workshop, applying incursion response principles to an exclusion pest and developing courses of action. <i>By May 2025</i>
		5. Contingency funding sources are identified that can be mobilised for rapid response to new incursions. <i>By May 2025</i>
Goal Two Stakeholder agencies and the community are informed of planned control works and their effectiveness	A. The community is informed about the risks of lagarosiphon spread and progress in management of lagarosiphon.	6. A LINZ communication plan is refreshed annually ⁴ with key messages to pass on to the community. <i>Annually</i>
		7. The location, nature, scale and timing of control works ⁵ is shared with the public in a timely, easy to navigate and understandable form. <i>By May 2024</i>
	B. Public documents and media releases concerning lagarosiphon management are coordinated and supported by the committee.	8. At least one appropriate media release related to lagarosiphon control works is shared and promulgated by two or more agencies via media or community information networks. <i>Annually</i>
	C. Regional Council and local community networks ⁶ outside of the stakeholder committee are informed and cognisant of the risks and opportunities regarding aquatic weed management.	9. At least one presentation is made to Regional Council and local community networks by the committee chair or delegate at a joint meeting or other initiative to directly share available information. <i>Annually</i>

³ E.g., Redevelopment of Wanaka Marina [May Marina Update – Wanaka Marina](#), Glendhu residential development and community jetty [Golf Course – Glendhu](#)

⁴ The TOR for Aquatic Weed Management Committees states that as the Chair, LINZ should receive all media approaches relevant to the Committee and the Management Plan

⁵ The LINZ Control work web viewer shows what, where and when weed control has been undertaken [Control Work Web Viewer - BML \(arcgis.com\)](#)

⁶ E.g., Otago Deep Lakes Management Working Group and Otago Inland Deep Lakes Technical Advisory Group that will include wider membership of agencies, community groups and experts [Media release: Increasing care for Otago's taonga lakes needs national support | Otago Regional Council \(orc.govt.nz\)](#)

Goal Three Lagarosiphon-free waterbodies are protected by early detection and rapid response	A. Surveillance for freshwater pests in the Otago region is best practice and co-ordinated between agencies with statutory responsibilities.	10. A regional aquatic pest surveillance programme is developed, with transparent prioritisation according to risk (spatial and temporal) and approach is reported to the committee. <i>By May 2025</i>
		11. Any aquatic pest findings from regional surveillance are reported to the committee as soon as practicable. <i>Ongoing</i>
		12. Shoreline surveillance for lagarosiphon is carried out under the LINZ programme using a transparent, risk-based, adaptive process. <i>Annually to biennially</i>
	B. New or more efficient surveillance or detection tools, or new use of existing tools, are assessed and adopted if appropriate.	13. At least one new surveillance or detection tool ⁷ or technique is adopted during the term of the current 10-year management plan. <i>By 2034</i>
Goal Four Risk of lake weed transfer is actively managed and reduced	A. The spread of lagarosiphon to other waterbodies is prevented and additional freshwater pests are not introduced via human-mediated pathways ⁸ .	14. Undertake summer monitoring of water users at designated sites under the 'Check, Clean, Dry' advocacy programme and report back to the stakeholder group ⁹ . <i>Annually</i>
		15. Analysis of responses to summer monitoring of water users at designated sites shows knowledge of freshwater pests (>50%) and the Check, Clean, Dry method exceeds 70% ⁹ . <i>Annually</i>
		16. The harbourmasters office develop a system to notify regional council staff for all on-water events, with sufficient notice for the provision of bespoke Check, Clean Dry advocacy. <i>By May 2025</i>
Goal Five Lagarosiphon is progressively contained and eradication gains are maintained	A. The Containment Line can shift south in response to progress in clearing weed beds	17. The Containment Line shifts to Fernburn Point <i>By May 2025</i>
		18. The Containment Line shifts to Waterfall Creek <i>By May 2028</i>
	B. Source weed beds of drift into the Eradication Zone are controlled	19. Modelled transport patterns ¹⁰ for weed fragments from potential source areas identify key weed beds to control. <i>By May 2025</i>

⁷ E.g., eDNA, automated detection using computer vision

⁸ Aligns with Mahika Kai and Biodiversity Policies in the Clutha/Mata-au Catchment: To encourage environmental and educational efforts to halt the spread of lagarosiphon and other pest species. Kāi Tahu Ki Otago Natural Resource Management Plan 2005. <https://www.waitaki.govt.nz/files/assets/public/files/our-services/planning-and-resource-consents/kai-kahu-ki-otago-natural-resources-management-plan-2005.pdf>

⁹ Aligns with Deliverable, KPI and target listed for Lagarosiphon regional priority under the [Biosecurity Operational Plan 2022-2023 \(orc.govt.nz\)](https://atlas.boprc.govt.nz/api/v1/edms/document/A3379094/content), % positive responses drawn from BOPRC Aquatic Pest Report 2019 <https://atlas.boprc.govt.nz/api/v1/edms/document/A3379094/content>.

¹⁰ Particle transport model developed from NIWA's hydrological model for the lake.

	C. Next priority and shoreline sequence for weed bed clearance is identified ¹¹ and agreed by stakeholders	20. A strategy and tactical approach is identified for the next priority weed control zone, outlining the order and methods for management. <i>By May 2025</i>
		21. New tools for sustained control of lagarosiphon (e.g., herbicides) are trialled and if appropriate adopted for more efficient control outcomes. <i>By May 2028</i>
	D. Shoreline units cleared of weed beds and the Eradication Zone are prioritised for maintenance according to risk.	22. No reversion of cleared areas and reinvasion by lagarosiphon weed beds is permitted. <i>Ongoing</i>

¹¹ Depending on progress under Goal 5, Objectives A and B.

10 Acknowledgements

Many thanks to NIWA staff present and past for images used in this document.

11 Glossary of abbreviations and terms

Progressive containment	To contain or reduce the geographic distribution of the pest to an area over time.
Sustained control	To provide for ongoing control of the subject to reduce its impacts and its spread to other properties
Eradication	To reduce the infestation level of the pest to zero levels in an area in the short to medium term.
Pathways	The method or route by which pests spread.
Vectors	The mechanism by which pests spread.
Transformer	Alien invasive species that severely modify and structure the systems that they invade, so named for their transformative detrimental impacts on aquatic ecosystems.
Weed cordons	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, retrieval or temporary mooring.
Surveillance	Searching for and documenting new incursions of pests.
Riskscape	The distribution of risk factors for pest invasion across a spatial landscape or across time.
Incursion	Record of a pest at a new site or where it has previously been eradicated.
Exclusion	To prevent the establishment of the pest that is present in New Zealand but not yet established in an area.
Delimitation	Determining the spatial extent of a pest species.
Adaptive management	An iterative process in which practitioners test approaches and then adjust them based on experience and actual changes.
Weed beds	Weed forms continuous growth of high cover along an extended area of shoreline.
Hygiene	Keeping boating amenity areas clear of weed to help prevent contamination of equipment and potential export or spread of fragments.

12 References

- ^{lvi} Biosecurity and Biodiversity Strategy. Toitū Te Whenua Land Information New Zealand. 1 June 2021
- ⁱ [Organisations and legislation for preventing freshwater pests: Freshwater pest species \(doc.govt.nz\)](#)
- ⁱⁱ [2202 \(fishandgame.org.nz\)](#)
- ⁱⁱⁱ [Council clarifies role of harbourmaster ahead of summer boating season \(qldc.govt.nz\)](#)
- ^{iv} Lagarosiphon was first reported as naturalised in New Zealand in 1950 and from the Otago Region, at Lake Wānaka, in 1972.
de Winton, M.D., Champion, P.D., Clayton, J.S., Wells, R.D.S. (2009) Spread and status of seven submerged pest plants in New Zealand lakes. *New Zealand Journal of Marine & Freshwater Research*, 43: 547–561.
- ^v Large weed beds can develop large beds at shorelines that are sheltered from prevailing winds and consequent wave action.
Caffrey, J., Acevedo, S. (2007) Status and Management of Lagarosiphon major in Lough Corrib 2007.
<http://www.fisheriesireland.ie/invasive-species-1/151-status-and-management-of-lagarosiphon-major-in-lough-corrib-2007-1/file>
- ^{vi} Nuisance surface reaching weed beds of lagarosiphon were limited to areas with a wind-wave fetch <4 km in Lake Taupo
Howard-Williams C., Davies, J. (1988) The invasion of Lake Taupo by the submerged water weed Lagarosiphon major and its impact on the native flora. *New Zealand Journal of Ecology*, 11: 13-19.
- ^{vii} Lagarosiphon weed beds are unlikely to form within river systems where flow velocity is greater than 0.5 m per second.
Matheson, F., Quinn, J., Hickey, C. (2012) Review of the New Zealand instream plant and nutrient guidelines and development of an extended decision making framework: Phases 1 and 2. NIWA Client Report HAM2012-081.
- ^{viii} Lagarosiphon weed beds are unlikely to form where there are frequent large flood flows (e.g., four times the median flow).
Haslam, S.L. (1978) *River Plants: the Macrophytic Vegetation of Watercourses*. Cambridge University Press, Cambridge, U.K.
- ^{ix} Transformer pests are those which transform an ecosystem in a profound and often irreversible direction
- ^x Buds are located at the shoot tip and some leaf bases, for instance, buds were found spaced on average at every 238 mm of stem length.
Johnstone, I.M., Coffey, B.T., Howard-Williams, C. (1985) The role of recreational boat traffic in interlake dispersal of macrophytes: A New Zealand case study. *Journal of Environmental Management*, 20: 263-279.
- ^{xi} 50% of fragments of lagarosiphon with a mean length was just 32 mm were found to regenerate.
Redekop, P., Hofstra, D., Hussner, A. (2016) *Elodea canadensis* shows a higher dispersal capacity via fragmentation than *Egeria densa* and *Lagarosiphon major*. *Aquatic Botany*, 130: 45–49.
- 80% of 10 mm long fragments regrew.
Coughlan, N. E., Armstrong, F., Baker-Arney, C., Crane, K., Cuthbert, R.N., Jansen, M.A.K., Kregting, L., Vong, G.Y.W., Dick, J.T.A. (2022) Retention of viability by fragmented invasive *Crassula helmsii*, *Elodea canadensis*, *Lagarosiphon major*. *River Research and Applications*, 38:1356-1361.
- ^{xii} 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 loss of viability associated with a 70% loss in fresh weight.

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

Lagarosiphon fragments (average 23 mm length) could survive at 85% humidity at 27°C for at least 4 hours.

Coughlan, N.E., Cuthbert, R.N., Kelly, T.C., Jansen, M.A.K. (2018) Parched plants: survival and viability of invasive aquatic macrophytes following exposure to various desiccation regimes *Aquatic Botany*, 150:9-15.

^{xiii} In a statistical modelling approach, the known distribution of lagarosiphon in New Zealand lakes was best explained by measures of recreational access (e.g., road development) and proximity of human population densities to infested lakes.

Compton T.J., de Winton, M., Leathwick J.R., Wadhwa, S. (2012) Predicting spread of invasive macrophytes in New Zealand lakes using indirect measures of human accessibility. *Freshwater Biology*, 57: 938–948.

^{xiv} Lagarosiphon is regarded an invasive weed in Australia, Ireland, The Netherlands, United Kingdom, France, Switzerland, Italy and Réunion Island.

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

Matthews, J., Beringen, R., Collas, F.P.L., Koopman, K.R., Odé, B., Pot, R., Sparrius, L.B., van Valkenburg, J.L.C.H., Verbrugge L.N.H., Leuven R.S.E.W. (2012) Knowledge document for risk analysis of the non-native curly waterweed (*Lagarosiphon major*) in the Netherlands.

<http://www.iucngisd.org/gisd/speciesname/Lagarosiphon+major>

^{xv} <https://niwa.co.nz/freshwater/management-tools/identification-guides-and-fact-sheets/freshwater-pest-speciesd> 2020

^{xvi} Lagarosiphon displaces native submerged vegetation within its depth range.

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

^{xvii} Burial and aging of the seed bank of native plants occurs with dominance by the major weeds, which would reduce native vegetation resilience to disturbance events.

de Winton, M.D., Clayton, J.S. (1996) The impact of invasive submerged weed species on seed banks in lake sediments. *Aquatic Botany*, 53: 31-45.

^{xviii} Lagarosiphon beds were found to create progressively stressful conditions of high pH and low CO₂ content under experimental conditions.

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

^{xix} Lagarosiphon beds in an Irish lough were associated with accentuated diurnal fluctuations of dissolved oxygen and pH.

Caffrey, J., Acevedo, S. (2007) Status and Management of *Lagarosiphon major* in Lough Corrib 2007.

<http://www.fisheriesireland.ie/invasive-species-1/151-status-and-management-of-lagarosiphon-major-in-lough-corrib-2007-1/file>

^{xx} Greater habitat complexity in vegetation is linked to greater diversity of aquatic insects.

Sloey, D., Schenck, T., Narf, R. (1996) Distribution of aquatic invertebrates within a dense bed of Eurasian Milfoil (*Myriophyllum spicatum* L.). *Journal of Freshwater Ecology*, 12(2): 303–313.

Celewicz-Góldyn, S., Kuczyńska-Kippen, N. (2017) Ecological value of macrophyte cover in creating habitat for microalgae (diatoms) and zooplankton (rotifers and crustaceans) in small field and forest water bodies. *PLoS ONE*, 12(5).

Greater habitat complexity in vegetation is linked to greater numerical abundance of aquatic insects (but not necessarily biomass).

Ferreiro, N., Feijóo, C., Giorgi, A., Rosso, J. (2014) Macroinvertebrates select complex macrophytes independently of their body size and fish predation risk in a Pampean stream. *Hydrobiologia*, 740(1): 191-205.

^{xxi} Differences have been detected in the composition of macroinvertebrates between invasive weed beds and native vegetation.

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

Caffrey, J., Acevedo, S. (2007) Status and Management of *Lagarosiphon major* in Lough Corrib 2007.

<http://www.fisheriesireland.ie/invasive-species-1/151-status-and-management-of-lagarosiphon-major-in-lough-corrib-2007-1/file>

^{xxii} Native fish (bully) predation rates on snails were significantly lower in *lagarosiphon* than in native beds.

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

^{xxiii} Freshwater mussels are excluded from dense beds of invasive macrophytes, possibly directly through occupation of lakebed, by modifying water currents and food availability, creating diurnal fluctuations in oxygen and pH, or by modifying sediments.

James, M. (1985) Distribution, biomass and production of the freshwater mussel *Hyridella menziesi* (Gray), in Lake Taupo, New Zealand. *Freshwater Biology*, 15: 307-314.

Burlakova, L.E., Karatayev, A.Y. (2007) The effects of invasive macrophytes and water level fluctuations on unionids in Texas impoundments. *Hydrobiologia*, 586: 291–302.

^{xxiv} Transformer pests change an ecosystem in a profound and often irreversible direction.

^{xxv} Large beds of canopy-forming weeds are associated with depressed quantity and quality of boating, swimming and nearshore recreation.

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

^{xxvi} Entanglement and drownings have been linked to invasive weed beds.

Getsinger, K., Dibble, E., Rodgers, J.H., Spencer, D. (2014) Benefits of controlling nuisance aquatic plants and algae in the United States: 12.

<http://www.cast-science.org/download.cfm?PublicationID=282524&File=1030b3a54e8a7b19997c7d3a20702ea2c5TR>

^{xxvii} Dense mats of weed provide good habitat for the snail hosts of parasites that cause ‘swimmer’s (duck) itch’.

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

^{xxviii} Weed strand creates odour and aesthetic issues on public foreshores.

<https://www.rnz.co.nz/news/ldr/462491/lake-weed-stench-plagues-rotorua-lakefront>

^{xxix} Submerged weeds in New Zealand have resulted in world record biomass and significant loss of generation potential.

Clayton, J., Champion, P. (2006) Risk assessment method for submerged weeds in New Zealand hydroelectric lakes. *Hydrobiologia* 570, 183–188.

^{xxx} Hydro-power water intakes are usually screened at the entry point (penstock) to prevent the ingress of debris that might otherwise damage infrastructure such as turbines. However, drifting submerged weeds can block penstock intake screens, restricting flow and causing unplanned outages.

Johnstone, I.M. (1986) Macrophyte management: An integrated perspective, *New Zealand Journal of Marine and Freshwater Research*, 20: 599-614.

^{xxxi} Densely growth of *Lagarosiphon* and other aquatic plants, blocking the flow of water in channels and clog fine-particle screens at drainage pump stations.

Tsujimoto, I.T., K., Nakashima, Y. (2022). Backwater effect of clogging of aquatic plants at fine-particle screens on inland flooding in Okayama. *Water*, 14(13), 1980.

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- xxxii In an economic assessment, lakefront property values were compared for US lakes with and without the presence of canopy-forming weed (*Myriophyllum spicatum*) and showed invasion corresponded to a 19% decline in mean property values.
Olden, J.D., Tamayo, M. (2014) Incentivizing the public to support invasive species management: Eurasian milfoil reduces lakefront property values. *PLoS One*, 9(10): e110458.
- xxxiii [Draft Land and Water Regional Plan: Proposed new rules and regulations for the Upper Lakes Rohe | Otago Regional Council \(orc.govt.nz\)](#)
- xxxiv Clayton, J.S., de Winton, M., Wells, R.D.S., Tanner, C.C., Miller, S.T., Evans-McLeod, D. (1989) *The aquatic vegetation of 15 Rotorua lakes*. Aquatic Plants Section. Ministry of Agriculture and Fisheries: 101.
- xxxv Eiswerth M.E., Donaldson S.G., Johnson W.S. (2000) Potential environmental impacts and economic damages of Eurasian watermilfoil (*Myriophyllum spicatum*) in western Nevada and northeastern California. *Weed Technology*, 14: 511–518.
- xxxvi Getsinger K., Dibble E., Rodgers, J.H., Spencer D. (2014) Benefits of controlling nuisance aquatic plants and algae in the United States: 12. <http://www.cast-science.org/download.cfm?PublicationID=282524&File=1030b3a54e8a7b19997c7d3a20702ea2c5TR>
- xxxvii Eiswerth M.E., Donaldson S.G., Johnson W.S. (2000) Potential environmental impacts and economic damages of Eurasian watermilfoil (*Myriophyllum spicatum*) in western Nevada and northeastern California. *Weed Technology*, 14: 511–518.
- xxxviii [Letter to MfE and DOC regarding the health of Otago's deep-water alpine lakes | Parliamentary Commissioner of Environment \(pce.parliament.nz\)](#)
- xxxix [Media release: Increasing care for Otago's taonga lakes needs national support | Otago Regional Council \(orc.govt.nz\)](#)
- xi *Biosecurity Act (1993)*
- xli National Pest Plant Accord: a cooperative agreement between central government agencies, local government agencies and the Nursery and Garden Industry Association
- xlii Legislation (Section 53 of the Conservation Act 1987) prohibited the intentional introduction of new organisms into waterways unless permitted by the Minister of Conservation.
- xliii [Check, Clean, Dry: preventing didymo and other pests | NZ Government \(mpi.govt.nz\)](#)
- xliv https://www.orc.govt.nz/media/10068/orc-regional-pest-management-plan-2019-29_final_corrected-21.pdf
- xlvi [Lake Wanaka Preservation Act 1973 No 107 \(as at 22 October 1998\), Public Act 12 No derogation from provisions of Act – New Zealand Legislation](#)
- xlvi [Guardians of Lake Wānaka: Statutory and advisory bodies \(doc.govt.nz\)](#)
- xlvi <https://www.mpi.govt.nz/dmsdocument/9464-National-Policy-Direction-for-Pest-Management-2015>
- xlviii [orc-regional-pest-management-plan-2019-29_final_corrected-21.pdf](#)
- xlix *ORC (2022) Lagarosiphon Management Plan for 2022-23*
- ^l <https://www.mpi.govt.nz/outdoor-activities/boating-and-watersports-tips-to-prevent-spread-of-pests/check-clean-dry/>
- li A range of methods have been proposed for removing pest organisms from boats prior to launching.
Miller, N., Richardson, P., Collins, E., Young, K. (2006) *Design and feasibility of wash-down stations for boating equipment entering the Rotorua lakes*. DOC research & development series 247. [Design and feasibility of wash-down stations for boating equipment entering the Rotorua Lakes \(doc.govt.nz\)](#)
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lii Hot water treatments are used on inspected craft wanting to enter Lake Tahoe that have been determined to be contaminated.

<https://tahoeboatinspections.com/>

liii A portable wash-down unit was deployed for the Rotorua Te Arawa lakes at events.

Lass, H. (2017) *Lake Biosecurity – local actions and results*. Lakes Water Quality Society Symposium, 31st August- 1st September 2017. Millenium Hotel, Rotorua.

liv Weed cordons are installed at eight locations across six Rotorua Te Arawa Lakes.

Lass, H. (2012) *Rotorua lakes weed cordons – a freshwater biosecurity tool*: 25-29. Eighteenth Australasian Weed Conference. The Sebel and Citigate Albert Park, Melbourne, Victoria, Australia. 8-11 October 2012 <http://caws.nzpps.org/awc/2012/awc201210251.pdf>

lv Suggested to be low density of <125 plants per 0.1 ha

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

lvi Use of jute hessian was successful in controlling lagarosiphon in areas of an Irish lough in as little as four months.

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

NIWA trials have shown that hessian (and denser coconut fibre) could successful remove lagarosiphon within five months.

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

lvii Jute hessian is biodegradable, lasting up to 10 months before beginning to disintegrate.

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

lviii Native charophytes establish on hessian treated areas as they can grow through the weave.

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

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

lix All uprooted weed material is discharged into a fine meshed collection bag.

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

lx Suction dredging has been used to eradicate submerged weed from a 610 m length of river in Texas, USA.

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

lxi A substantial reduction in weed biomass and greater native plant diversity was measured 1 year later.

Eichler, L.W., Bombard, R.T., Sutherland, J.W., Boylen, C.W. (1993) *Suction harvesting of Eurasian watermilfoil and its effect on native plant communities*. *Journal of Aquatic Plant Management* 31:144-148.

lxii Weeds can be removed using a suction dredge or diver-operated venturi suction pump. This method is slow and only suited to small areas with good underwater visibility.

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

lxiii Diquat is a contact herbicide that desiccates and defoliates plant tissue that come into contact with the herbicide

Clayton, J., Severne, C. (2005) *Review of diquat reports of relevance to iwi values in Lake Karapiro. NIWA Client Report HAM2005-136, prepared for Environment Waikato: 10.*

lxiv Typical applications of diquat for weed control result in dose concentrations of about 0.1 – 0.4 parts per million of water.

Netherland, M.D. 2014. *Chemical control of aquatic weeds. In Biology and control of aquatic plants: a best management practices handbook. 3rd ed. Edited by L. Gettys, W. Haller, and D. Petty. Aquatic Ecosystem Restoration Foundation, USA. pp. 71–88.*

lxv Introduced freshwater weeds are more susceptible to diquat than the most common native freshwater plants: charophytes.

Clayton, J.S.; Tanner C.C. (1988) *Selective control of submerged aquatic plants to enhance recreational uses of water bodies, SIL Proceedings, 1922-2010, 23:3, 1518- 1521.*

Tanner, C.C.; Clayton J.S.; Coffey, B.T. (1990) *Submerged-vegetation changes in Lake Rotorua (Hamilton, New Zealand) related to herbicide treatment and invasion by Egeria densa, New Zealand Journal of Marine and Freshwater Research, 24:1, 45-57.*

Kelly, C.L.; Hofstra, D.E.; de Winton M.D. Hamilton D.P. 2012. *Charophyte germination responses to herbicide application. Journal of Aquatic Plant Management 50: 150-154.*

lxvi Diquat efficacy is reduced in turbid water or where plants are covered in organic matter or deposits of silt, which can rapidly bind the diquat.

Clayton, J, Matheson, F. (2010) *Optimising diquat use for submerged aquatic weed management. Hydrobiologia, 656: 159-165.*

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

lxvii The use of diquat products on aquatic sites does not pose any health impacts of concern to people swimming in treated waters (ponds, lakes, reservoirs, etc).

McCarthy, S. (2019) *Completion of diquat dibromide mitigation for swimmer exposure. Department of Pesticide Regulation, California Environmental Protection Agency.*

lxviii The ecological risk of diquat is minimised by a very short exposure time when applied to waterbodies to control weeds. Rapid diquat dissipation from the water by binding to sediment and particulate matter means it is bioavailable for short exposure durations in situ.

Ritter, A.M., Shaw, J.L., Williams, W.M., Travis, K.Z., 2000. *Characterizing aquatic ecological risks from pesticides using a diquat dibromide case study. I. Probabilistic exposure estimates. Environ. Toxicol. Chem. 19, 749–759.*

Langeland KA, Fox AM, Laroche FB et al (1994) *Diquat distribution in water after application to submersed weeds. Water Res Bull 30:93–97*

Langeland KA, Warner JP (1986) *Persistence of diquat, endothall and fluridone in ponds. J Aquat Plant Manag 24:43–63*

lxix Scientific papers have concluded that diquat under realistic scenarios of use for freshwater weed control has negligible risk for survival of non-target aquatic organisms.

Breckels, R.; Kilgour, B. (2018). *Aquatic herbicide applications for the control of aquatic plants in Canada: Effects to nontarget aquatic organisms. Environmental Reviews. 26. 10.1139/er-2018-0002.*

Campbell, K.R., Bartell, S.M. and Shaw, J.L. (2000). *Characterizing aquatic ecological risks from pesticides using a diquat dibromide case study. II. Approaches using quotients and distributions. Environmental Toxicology and Chemistry, 19: 760-774.*

Bartell, S.M., Campbell, K.R., Lovelock, C.M., Nair, S.K. and Shaw, J.L. (2000). *Characterizing aquatic ecological risks from pesticides using a diquat dibromide case study III. Ecological process models. Environmental Toxicology and Chemistry, 19: 1441-1453.*

lxx No diquat was detected in sediment of a lake treated for nine years, where application quantities would have been detectable if diquat was accumulating in the sediment and not breaking down.

Hoyer, M.V.; Haller, W.T.; Ferrell, J.; Jones, D. (2020) *Legacy herbicides in lake sediments are not preventing the growth of submersed aquatic plants in Lake Istokpoga. Journal of Aquatic Plant Management 58:47-54.*

No accumulation of diquat could be detected in sediment at sites in the Rotorua Te Arawa Lakes that have been regularly treated for decades.

Clayton, J., Severne, C. (2005) Review of diquat reports of relevance to iwi values in Lake Karapiro. NIWA Client Report HAM2005-136, prepared for Environment Waikato: 10.

lxxii 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 m² of surface-matted hydrilla (*Hydrilla verticillata*) per hour.

Haller, W.T., Jones, D.K. (2012) Technology and improved efficacy of mechanical control of hydrilla. *Aquatics*, Fall: 17-19.

lxxiii 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.

McComas, S. (2011) Literature Review on Controlling Aquatic Invasive Vegetation with Aquatic Herbicides Compared to Other Control Methods: Effectiveness, Impacts, and Costs. *Blue Water Science Report for Minnehaha Creek Watershed District*: 16.

lxxiv Aquarius Systems Ltd HM420 model navigates at 3-4 km/h and can accommodate 10 m³ of wet weed which takes c. 6 min to load (if the weed is dense). Can clear a ca 5 ha area of dense weed in approximately 120 h with a 50 m distance to offload onshore. Maximum cutting depth is 1.2 m (H Emeny pers comm., Lakeweed Harvesters & Contractors, August 2015).

lxxv Disturbance of bottom sediments during harvesting operations results in localised increases in water turbidity and dissolved nutrient concentrations.

James, W.F., Barko, J.W., Eakin, H.L. (2002) Water quality impacts of mechanical shredding of aquatic macrophytes. *Journal Aquatic Plant Management*, 40: 36-42.

lxxvi Use of commercial harvesters is known to entrap and kill fish and invertebrates that live in the harvested weed.

Wile, I. (1978) Environmental effects of mechanical harvesting. *Journal of Aquatic Plant Management*, 16: 14-20.

Haller, W.T., Shireman, J.V., DuRant, D.F. (1980) Fish harvest resulting from mechanical control of hydrilla. *Trans. American Fisheries Society*, 109: 517-520.

Engel, S. (1990) Ecological impacts of harvesting macrophytes in Halverson Lake. *Journal of Aquatic Plant Management*, 28: 41-45.

lxxvii Assuming modest relative growth rates for lagarosiphon 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 for lagarosiphon of up to 0.063 day⁻¹.

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

James, C.S., Eaton, J.W., Hardwick, K. (2006) Responses of three invasive aquatic macrophytes to nutrient enrichment do not explain their observed field displacements. *Aquatic Botany*: 84(4): 347-353.

lxxviii If non-target plants are preferred to target weed species then the non-target plants will be consumed first.

Hofstra, D., Rowe, D.K., Clayton, J.S. (2014) Assessment of grass carp use for aquatic weed control: environmental impacts, management constraints and biosecurity risks in New Zealand waters. NIWA Client Report HAM2014-061, MPI14202: 158. [Assessment of Grass Carp use FINAL Report for MPI 12Aug2014 \(doc.govt.nz\)](#)

lxxix Where grass carp are used for weed control, containment structures to ensure that the grass carp remain within the waterbody are often required.

Hofstra, D., Rowe, D.K., Clayton, J.S. (2014) Assessment of grass carp use for aquatic weed control: environmental impacts, management constraints and biosecurity risks in New Zealand waters. NIWA Client Report HAM2014-061, MPI14202: 158. [Assessment of Grass Carp use FINAL Report for MPI 12Aug2014 \(doc.govt.nz\)](#)

lxxx [New weapon in fight against invasive aquatic weeds | NIWA](#)

lxxxi Mode of action on submerged weeds is similar to the contact activity on terrestrial plants, where wilting and leaf desiccation is the commonly observed symptom.

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

lxxxii Translocation of endothall to the roots of foliar treated submerged weeds has been confirmed.

Ortiz, M., Nissen, S.J., Gray, C.J. (2019) Endothall behavior in *Myriophyllum spicatum* and *Hydrilla verticillata*. *Pest management Science* 75: 2942-2947.

lxxxiii Hornwort exposed to endothall were killed irrespective of turbidity at up to 25 NTU.

Hofstra, D.E., Clayton, J.S., Getsinger, K. (2001) Evaluation of Selected Herbicides for the Control of Exotic Submerged Weeds in New Zealand: II. The Effects of Turbidity on Diquat and Endothall Efficacy. *Journal of Aquatic Plant Management* 39: 25–27.

lxxxiv Endothall is required to be in contact with the target plants at a treatment concentration for hours to days in order to be effective.

Slade, J.G., Poovey, A.G., Getsinger, K.D. (2008) Concentration–exposure time relationships for controlling sago pondweed (*Stuckenia pectinata*) with endothall. *Weed Technology* 22(1): 146–150.

Clements, D., Butler, K.L., Hunt, T.D., Zhiqian, L., Dugdale, T.M. (2018) Efficacy of endothall dimethylalkylamine salt applied to static irrigation channels during winter to control aquatic weeds in temperate Australia. *Journal of Aquatic Plant Management* 56: 84–92.

lxxxv Endothall killed coontail, and lagarosiphon but not egeria.

Hofstra, D.E., Clayton, J.S. (2001) Evaluation of selected herbicides for the control of exotic submerged weeds in New Zealand: 1. The use of endothall, triclopyr and dichlobenil. *Journal of Aquatic Plant Management* 39: 20–24.

lxxxvi Significant reductions in biomass for target species including lagarosiphon were achieved by one to two applications at up to 0.4 mg per litre, as long as pH was less than 8.5.

Hofstra D, Clements D, Rendle D, Champion P (2021) Evaluation of flumioxazin on seven submersed macrophytes in New Zealand. *J Aquat Plant Manag* 5:27–34

lxxxvii ProcettaCOR trials demonstrated the potential for controlling lagarosiphon, with further large-scale screening required to confirm control among field site applications. Lagarosiphon was the most sensitive species evaluated.

Howell, A.W., Hofstra, D.E., Heilman, M.A., Richardson, R.J. (2022) Susceptibility of native and invasive submersed plants in New Zealand to florypyrauxifen-benzyl in growth chamber exposure studies. *Invasive Plant Science and Management*, 15:133-140.

lxxxviii Low-dose, extended exposure concept for endothall treatment were found to be efficacious and logistically feasible.

Sisneros, D., Lichtwardt, M., Greene T. (1998) Low-Dose Metering of Endothall for Aquatic Plant Control in Flowing Water. *Aquat. Plant Manage.* 36: 69-72 [Low-Dose-Metering-of-Endothall-for-Aquatic-Plant-Control-in-Flowing-Water-UPL-Aquatics-1998.pdf \(uplaquatics.com\)](#)

lxxxix Four insects have been released to control hydrilla, but only two of these insects are established, and only one is commonly associated with hydrilla in the southeastern U.S. None of the insects have been able to adequately control or stress rapidly increasing hydrilla populations.

[Biological Control - Plant Management in Florida Waters - An Integrated Approach - University of Florida, Institute of Food and Agricultural Sciences - UF/IFAS \(ufl.edu\)](#)

xc The leaf-mining fly *Hydrellia lagarosiphon* (Diptera: Ephydriidae) is being considered as a classical biological control agent in New Zealand and Ireland against the invasive species *Lagarosiphon major*.

Mangan R., Baars J (2016) Can leaf-mining flies generate damage with significant impact on the submerged weed *Lagarosiphon major*? *BioControl* 61(6).

Paynter, Q. (2013) Feasibility of biocontrol of *Lagarosiphon major* in New Zealand. Envirolink grant 1248-HZLC93. [Feasibility of biocontrol of Lagarosiphon major in New Zealand \(landcareresearch.co.nz\)](#)

xcii Experimental mesocosm studies showed larvae had a major effect on lagarosiphon and four other invasive submerged weeds.

Redekop, P., Gross, E.M., Nuttens, A., Hofstra, D.E., Clayton, J.S., Hussner A. (2018) *Hydraula nitens*, the only native aquatic caterpillar in New Zealand, prefers feeding on an alien submerged plant. *Hydrobiologia* volume 812:13–2.

xciii Muller C, Hofstra D, Champion P (2021) Eradication economics for invasive alien aquatic plants. *Manag Biol Invasions* 12:253–271.

^{xciii} Wave fetch perpendicular to shorelines has been shown to affect the formation of large stands of lagarosiphon in Lake Taupō where fetch exceeded 4 km, only small, scattered patches and single strands of lagarosiphon less than 1 m in height occurred.

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

^{xciv} Lagarosiphon spread rapidly in Lake Taupo, with less than two years between the time of its introduction at the north end of the lake to its appearance at the south end. In Lake Wānaka lagarosiphon quickly spread throughout the southern half of the lake within the first 4 years of colonisation, in spite of intensive weed control measures. Within 5 years of hornwort being first recorded in Lake Tarawera (41 km²), it occurred at 52% of surveyed sites. In the hydrologically linked Waikato hydro lakes, downstream invasion followed by dominance by weeds including lagarosiphon, hornwort and egeria occurred within 2-5 years of their first record in the system. Upstream spread of egeria through the Waikato Hydro lakes was slower and linked to recreational boat traffic. Spread of lagarosiphon through five of the Rotorua Te Arawa Lakes occurred within 10-15 years of the first lake record.

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

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^{xcv} ORC (1996) *Pest Plant Management Strategy for the Otago Region*. ISBN 0-908922-31-0. 42 pp.

^{xcvi} Lake Wanaka Lagarosiphon Management Team (2005) *A 10 Year Lagarosiphon Management Plan for Lake Wanaka: 2005 -2015*.

^{xcvii} Clayton, J. (2007) *Lake Wanaka inspection February 2007*. NIWA Client Report: HAM2007-025. 19 pp.