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

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

August 2016

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NIWA CLIENT REPORT No: HAM2016-040
Report date: August 2016
NIWA Project: BML16201

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

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Executive summary

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

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

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

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

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

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

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

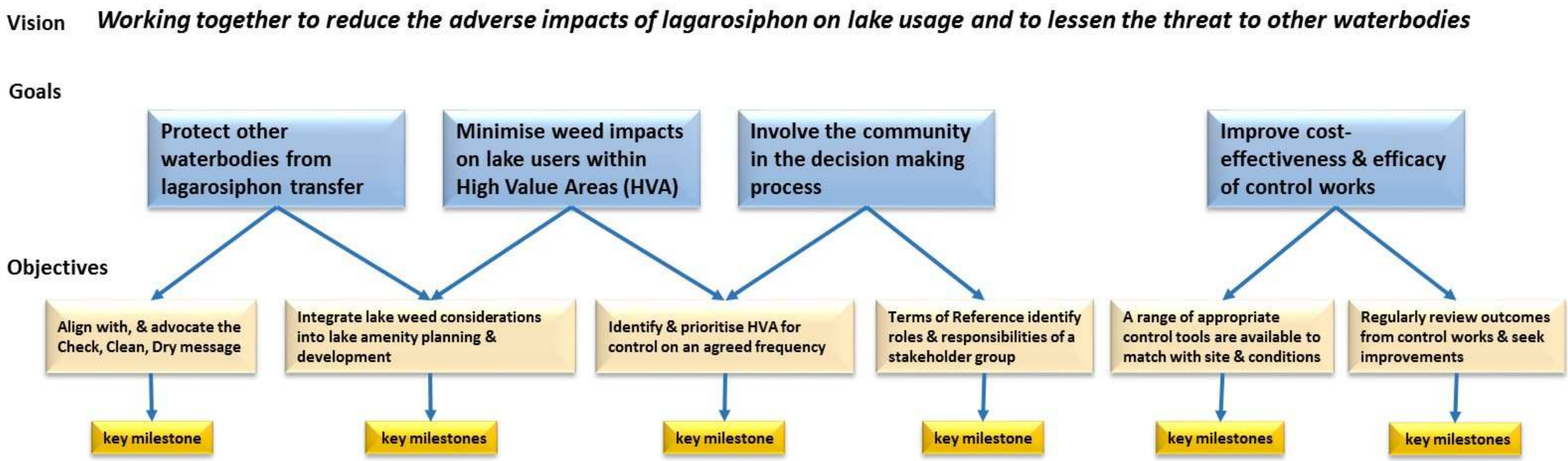

Figure 1: High level vision statement, goals and integrated objectives of the lagarosiphon management plan for the Lake Dunstan 2016 - 2025.

1 Introduction

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

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

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

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

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

2 Ten Year Management Plan 2016 – 2025

2.1 Vision statement

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

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

2.2 Management Goals

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

Goal 1: Protect other waterbodies from lagarosiphon transfer.

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

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

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

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

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

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

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

2.3 Management Objectives

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

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

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

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

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

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

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

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

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

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

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

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

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

3 Agencies: interests and responsibilities

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

Land Information New Zealand

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

Central Otago District Council

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

Contact Energy Limited

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

Cromwell and Districts Community Trust

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

Guardians of Lake Dunstan

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

Otago Fish and Game Council

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

Otago Regional Council

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

The Clutha Fisheries Trust

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

Kāi Tahu

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

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

4 Background

Lagarosiphon ecology and management status

Lagarosiphon (*Lagarosiphon major* (Ridley) Moss ex Wager), also known as oxygen weed or African elodea, is a submerged, perennial macrophyte of freshwaters. Plants are characterised by strongly recurved leaves that are arranged spirally (see frontispiece) and close-packed along each stem, even more so towards the shoot apex[1]. Stems are long, slender, much branched and brittle. In older plants, a 'root crown' of woody stems is found at the base of the plant with roots extending into the sediment. Roots can also develop from nodes along the stem, which aid in the horizontal spread and colonisation by lagarosiphon. Even in its native range (Southern Africa) lagarosiphon reproduces primarily by vegetative means[2], and rarely fruits[3]. Lagarosiphon has been recognised as invasive in Ireland[4], the Netherlands[5] United Kingdom, France, Belgium, Switzerland, Italy, Reunion, as well as New Zealand[6].

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

Lagarosiphon reproduction in New Zealand is entirely vegetative through stem fragmentation or horizontal spread from fallen stems. Buds are located at the apices of plants and at intervals at nodes along the stem. On average, lagarosiphon has one bud every 238 mm of stem length[8]. The minimal viable fragment size is not known, however is thought to be relatively small based on a reported 7.5 mm length (including a bud) for viable fragments of the related weed *Egeria densa*[9]. Viable apical fragments of 250 mm length were able to survive out of water for 20 hours at 20°C and 50% relative humidity, with death associated with a 70% loss in fresh weight[8]. Both this ability for small fragments to act as propagules, and short-term resistance to desiccation, means lagarosiphon may establish and form a new infestation at a new site from the transport and survival of just one viable fragment.

Human activities facilitate the spread of viable fragments via cultivation and release of plants or deliberate and accidental transfer between waterbodies. Although waterfowl have been suggested to spread weed there is no evidence they are a vector for lagarosiphon. Instead lagarosiphon distribution in lakes is significantly associated with boating and fishing activities[8]. In a statistical modelling approach the known distribution of lagarosiphon in New Zealand lakes was best explained by road development and human population densities around infested lakes as measures of recreational access[10].

Lagarosiphon was first reported as a naturalised species in New Zealand in 1950. It was introduced by the aquarium and pond plant trade[11] and initially spread via domestic sales of plants. Subsequently, spread has been mainly by recreational boat traffic between lakes. The first record of lagarosiphon in Lake Wanaka was in 1972[12]. Lagarosiphon is present in Lake Wanaka, the Clutha River, Lake Dunstan and Kawarau River, with records also in Canterbury, West Coast and Southland Regions (Figure 2). However, there remain numerous lakes in the vicinity that have not been invaded by lagarosiphon (Figure 2).

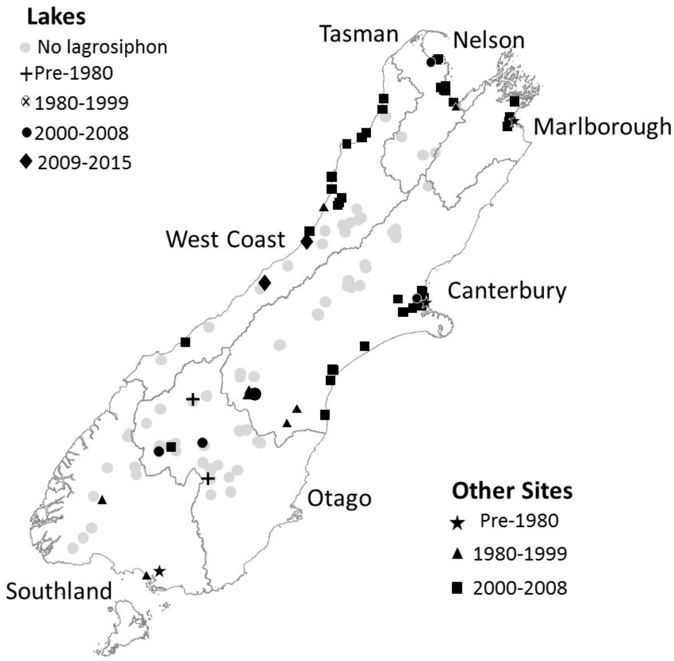

Figure 2: Distribution of lagarosiphon records in the South Island, but note some small sites have since been eradicated. Map modified from de Winton et al. (2009).

Once present in a lake, lagarosiphon can grow to a depth of 6.5 m, and up to 5 m in height. It can develop large beds at shorelines that are sheltered from prevailing winds and consequent wave action[13 14]. For instance, nuisance surface reaching weed beds were limited to areas with a wind-wave fetch <4 km in Lake Taupo[14], but subsurface bands of weeds and scattered colonies may develop over time on more exposed shorelines. Weed beds are also more restricted along steep shorelines.

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

The Regional Pest Management Strategy for Otago Region[15] lists lagarosiphon as being managed for containment and amenity in specified 'Lagarosiphon High Value Areas' (HVA's) in Lake Dunstan and the Clutha River. Lagarosiphon has a 'Containment' status in the southern region of Lake Wanaka and elsewhere in Otago Region it is designated a 'Total Control Species'. The Operational Plan for the Pest Management Strategy for Otago that covers the period 2009 to 2019[16] states a key activity as 'monitor the spread of Lagarosiphon'… 'where they are known to exist, and those water bodies with risk of establishment'. Lagarosiphon is also noted in Regional Pest Management Strategies for eight other regions including adjacent West Coast, Canterbury, and Southland Regions. Additional legislation (Section 53 of the Conservation Act 1987) prohibited the intentional introduction of new organisms into waterways unless permitted by the Minister of Conservation.

Known ecological impacts

Impacts by lagarosiphon are associated with the plants architecture and typically high biomass, which differs fundamentally from the native plant assemblages found in New Zealand lakes. Lagarosiphon is considered to have a competitive advantage over native submerged plants in colonising new habitats easily[17], by shading native plants through the development of an extremely dense subsurface canopy and by having a physiological advantage over potential competitors[18]. Consequently, lagarosiphon displaces and excludes native vegetation leading to monospecific beds of low diversity[1 19].

Differences have been detected in the composition of aquatic insects, termed macroinvertebrates, between lagarosiphon beds and native vegetation, with increased dominance by chironomids and snails in lagarosiphon beds but no obvious difference in overall diversity[13 20]. In Lake Wanaka the abundance of macroinvertebrates was higher per unit area within lagarosiphon beds than native vegetation[20], yet macroinvertebrate abundance was enhanced per unit macrophyte biomass where channels were cut through the lagarosiphon in Lake Dunstan[21]. This inconsistency may be related to lagarosiphon biomass, which was 12 fold greater in Lake Dunstan. It is thought that lagarosiphon may reduce fish access to macroinvertebrate food[20], whereas cut channels within large weed beds may enhance fish access and feeding[21].

Dense lagarosiphon beds restrict water movement and reduce light and may locally modify water chemistry. Lagarosiphon beds in an Irish lough were associated with accentuated diurnal fluctuations of dissolved oxygen and pH[13] and found to create progressively stressful conditions of high pH and low CO_2 content under experimental conditions[22]. Lagarosiphon beds in Lake Wanaka were found to be more productive (carbon fixation) than native vegetation in the comparable depth zone, with higher productivity again suggested for large weed beds in more nutrient enriched New Zealand lakes[20]. This productivity may contribute to the observation that dense lagarosiphon beds accumulate deep deposits of flocculent organic mud[13].

History of lagarosiphon infestation of the Clutha River and Lake Dunstan

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

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

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

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

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

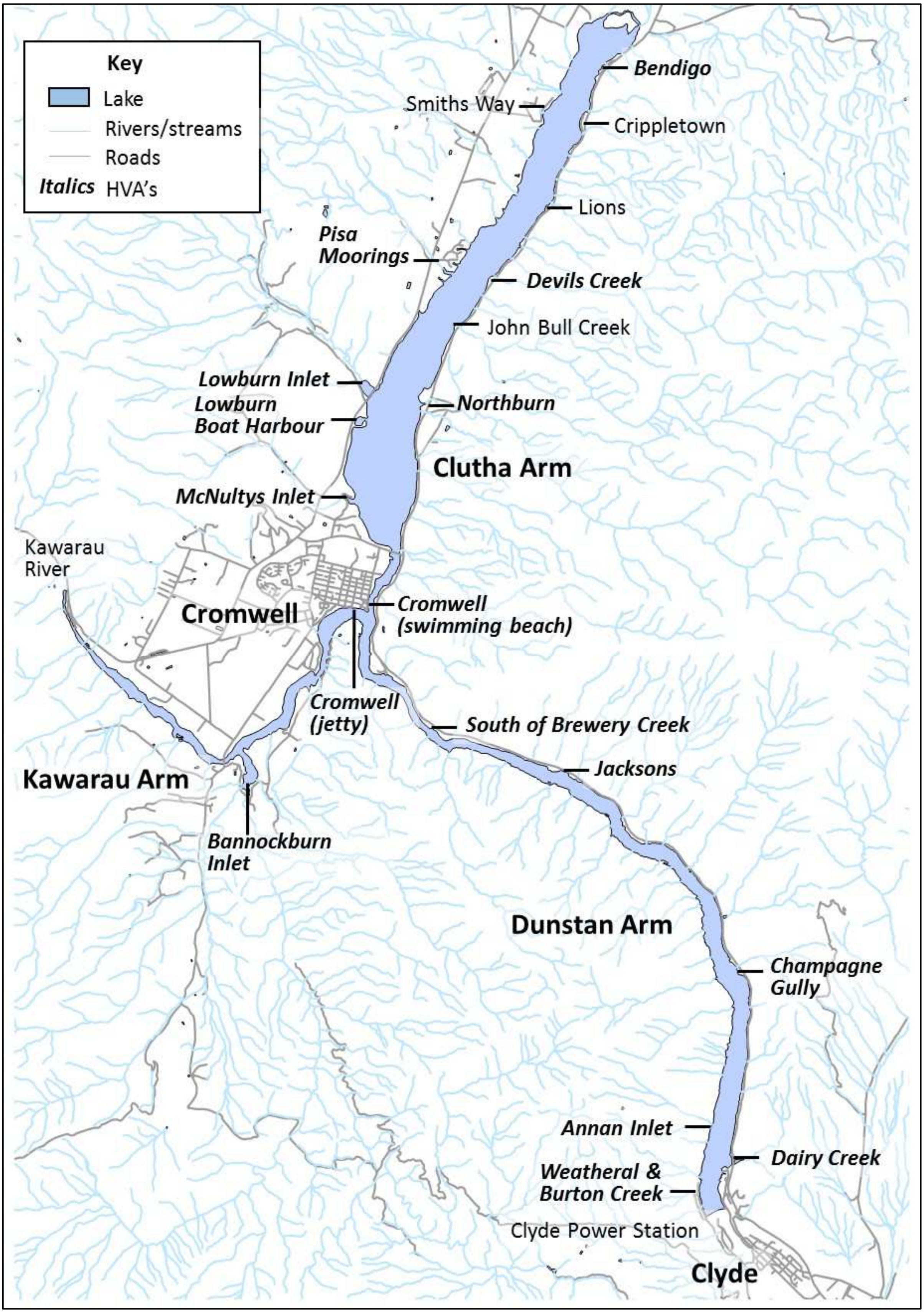

Figure 3: Map of the Lake Dunstan with amenity areas as noted in Clutha River/Mata-au Plan[41], with current (2016) HVA's[15] shown in italics.

Values at risk

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

Residential and lifestyle properties flank various parts of the lake including around inlets (Pisa Moorings, Lowburn and Bannockburn Inlets), Northburn, and Cromwell Township (Figure 3). Local property values can be reduced by lake weed development. In an economic assessment comparisons between lakefront property values at US lakes with and without the presence of canopy-forming weed (*Myriophyllum spicatum*) showed invasion corresponded to a 19% decline in mean property values[28]. Nevertheless, actual impacts for New Zealand lakes cannot be stated without specific analysis of the value of properties related to public perception of acceptable levels of weed.

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

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

Economic estimates of weed impacts on recreation are rare. In one study of a submerged weed, hydrilla, on a Florida lake (108 km^2), recreational values at risk from hydrilla were estimated at US$857,000 annually[32]. The willingness to pay by users to preserve recreation where it was deemed at risk from invasive aquatic weeds was estimated at US$4.62 per person per day[32].

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

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

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

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

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

5 Current status

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

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

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

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

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

6 Scenario of no management

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

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

7 Control options

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

There are two **herbicides** registered for use in New Zealand freshwater; diquat and endothall. They are contact herbicides that desiccate and defoliate plant tissue that come into contact with the herbicide[42 43]. The herbicides are highly effective against lagarosiphon yet have far less effect, or no effect, on native submerged plants. The outcome of successful treatment is a substantial reduction in the standing biomass of weed beds, with control of lagarosiphon expected to last for a season or up to one year from treatment.

Diquat is a widely used herbicide[44] that is relatively fast acting[45]. The active ingredient is diquat dibromide, with a concentration of 1 mg per litre (i.e., a 1:1,000,000 dilution) recommended to control weeds. Diquat can be applied by boat using surface booms or subsurface injection via trailing hoses or booms. Helicopter application is appropriate for large areas under suitable weather conditions. Diquat is applied at a rate of 30 litres per ha water surface, regardless of water depth, with over 0.5 m depth further diluting applied diquat to <1 mg per litre[42]. However, weed control has been achieved with application through several metres depth, at extremely low concentrations, as long as a sufficient contact time with plant tissue is achieved. Diquat performance is best in dense weed beds that retain the herbicide for longer. Effectiveness can also be enhanced by the addition of gelling agents that help place the herbicide within the weed bed. Double application of the herbicide at half application rates is also thought to extend the contact time. Diquat efficacy can be reduced in turbid water[46] or where plants are covered in organic matter or deposits of silt, which can rapidly bind and deactivate the diquat. Therefore checks of plant and water conditions are a necessary step before proceeding with application.

Diquat has negligible risk to human health and aquatic biota at the concentrations applied to the aquatic environment[42]. It is rapidly absorbed by plants and it tightly binds (adsorbs) to both inorganic and organic compounds within the water and bottom sediments. This means diquat is available in the water column for a very short time-frame (minutes to hours). Adsorbed diquat has no residual toxicity, is not biologically active and is degraded slowly by microbial organisms within sediments. No accumulation of diquat could be detected in sediment at sites that have been regularly treated for decades[47].

The advantage of endothall over diquat is that it is not deactivated by turbid water or dirty plant surfaces. However, a much longer contact time is required for effective control. Eradication of lagarosiphon has been achieved in smaller water bodies using this herbicide[48]. Further research to evaluate endothall as a potential control tool in a large lake such as Lake Dunstan is required before this option could be recommended.

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

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

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

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

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

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

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

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

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

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

8 Management strategies

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

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

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

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

9 Key milestones

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

10 Site Prioritisation Model

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

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

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

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

11 Record keeping

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

12 Reviews and annual process

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

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

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

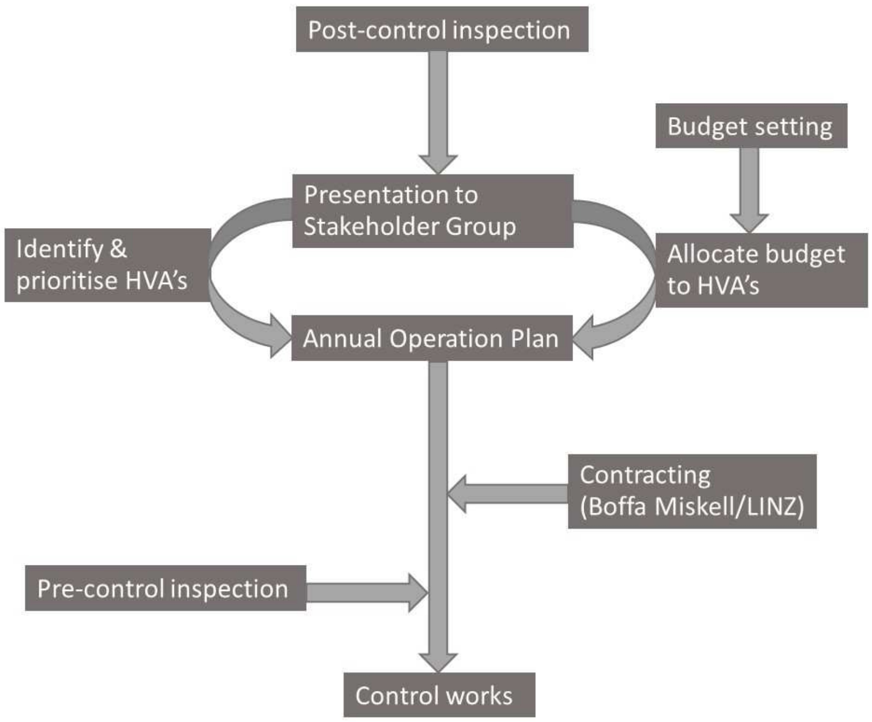

Figure 5: Annual process for planning the control works for Lake Dunstan.

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

13 Risks

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

Funding loss

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

Unrealistic public expectations

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

Public opposition to control tools

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

Lake conditions constrain works

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

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

14 Acknowledgements

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

15 Glossary of abbreviations and terms

Containment	Containing pests within a specified (usually restricted) range.
Control	Reduction of impacts through management action.
Eradication	The permanent removal of the entire pest population at a site.
Harvesting	Removal of weed biomass from a lake after cutting.
Sustained control	To provide for ongoing control of the pest to reduce its impacts and its spread to other properties.

Appendix A Review of potential control methodologies

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

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

Method	Effectiveness	Relative cost	Advantages	Disadvantages
Diquat herbicide	Capable of removing >90% of biomass, control can last for one growth season, unlikely to achieve site eradication.	Moderate cost $1.6k per ha (permitted activity).	Large areas can be controlled quickly, slows recovery as plants reallocate reserves to undamaged buds, moderately selective, few adverse effects.	May be deactivated in turbid water, lake currents may remove or dilute herbicide, woody stems & root crowns highly resistant.
Endothall herbicide	Capable of removing >90% of biomass, control lasts at least a growth season, unlikely to achieve site eradication.	Moderate to high cost (EPA approval required).	Not deactivated in turbid water, partially selective, few adverse effects, aqueous or pellet formulations.	Needs a long contact time, suitable for small waterbodies or enclosed areas, use requires additional NZEPA approvals.
Dichlobenil herbicide	Up to 100% control in suitable sites[4].			Not registered for aquatic use in New Zealand.
Grass carp	Not considered feasible for Lake Dunstan due to need for containment. Need stocking at sufficient density for sufficient time to remove target weed.	Very high cost (containment structure, approvals process).	Can eradicate lagarosiphon if all requirements in place (number of fish for long enough).	Unlikely to be contained in the lake, browsing at low temperatures <16°C may limit effectiveness, but may remove all submerged plants.
Classical biocontrol (host-specific insect)	Suppression of high biomass possible, will not achieve site eradication, may not achieve reduction at desired locations (i.e., cannot target specific sites/HVAs).	Development & testing costs high (national funding level) but release costs likely to be low	Potentially self-sustaining control agent populations achieved.	Not yet available in NZ, uncertainty over effectiveness, little success in USA.
Mycoherbicide (inundative biocontrol)	Capable of removing >90% of biomass, control lasts at least a growth season, site eradication possible.	Development & testing costs high.	Impact is localised and contained to the treatment area.	Not yet available, uncertainty over effectiveness.

Method	Effectiveness	Relative cost	Advantages	Disadvantages
Water drawdown 4 to 5 m for c. 2 weeks.	Desiccation or freezing can reduce biomass temporarily.	Loss of hydro-generation, loss of recreational use.	Relatively easy if water level control structure allows and necessary consents for drawdown in place.	Huge impacts on recreational usage, Large adverse environmental effects likely (erosion, loss of fish habitat).
Bottom lining (new biodegradable materials).	Amenity control in limited areas, medium-term control (up to a few years), control in 4-5 months[67] [68].	High cost as labour intensive ($30,000 per ha).	New biodegradable materials are easier to lay, may act as geotextile in stabilising sediments when weed removed and facilitate native plant recovery.	Requires consent, feasible for limited areas, requires reduction of weed biomass first, sedimentation allows re-colonisation of area, lining can be dislodged by wave/currents.

Appendix B Selection of control methodologies against criteria

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

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

Appendix C Amenity development at HVA's

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

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

Appendix D Proposed site ranking

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

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

Appendix E Overview of milestone activities by year

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

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

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