BEST MANAGEMENT PRACTICES FOR AQUATIC VEGETATION CONTROL IN STORMWATER WATERBODIES

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ABSTRACT

Auckland Council is responsible for the development and operation of a stormwater network across the region. Within this stormwater network, aquatic vegetation (including plants, unicellular and filamentous algae) can have both a positive and negative role in stormwater management and water quality treatment, as well as impact on passive and active amenity. The situations where management is needed to control aquatic vegetation are not always clear, and an inability to identify effective, feasible and economical control options may constrain management initiatives.

Thirty-five vegetation management practices (biological, chemical or physical) were evaluated, that could be potentially employed to enable better decision-making on aquatic vegetation management within stormwater systems. Each practice was considered in terms of opportunities and constraints, uncertainties, performance track record, indicative cost, and ease of implementation. Specific operation, maintenance, monitoring and reporting requirements were also outlined.

Whilst the study focussed on the Auckland environment, the outcomes should be of benefit to all practitioners managing freshwater wetlands, lakes and ponds in New Zealand.

KEYWORDS

Aquatic Vegetation, Freshwater, Stormwater, Management, Decision-making

PRESENTER PROFILE

Wolfgang Kanz graduated with a Masters in Applied Environmental Science from the University of KwaZulu-Natal, South Africa. His training and experience is in natural resource management, in particular anthropogenic impacts on the natural environment. Wolfgang is responsible for specialist ecological advice within the Auckland Council Stormwater Unit.

1 INTRODUCTION

Auckland Council (AC) is responsible for the development and operation of a stormwater network across the region to protect ratepayers' properties against flooding and avert risks to citizens and the environment. Additional management objectives have arisen from the recognition of the role of the stormwater network in providing ecosystem services and amenity values for the area.

Aquatic vegetation, including filamentous and unicellular algae, can contribute to the processing or retention of nutrients and contaminants, attenuate flows, and provide habitat or food for biota. However, it may also be necessary to reduce or remove vegetation biomass due to potential negative effects such as clogging of outlets, low dissolved oxygen, and decreased amenity. Drivers for aquatic vegetation management include ecological, economic, and social considerations.

The Aquatic Plant Management Society (USA) define control as: 'techniques used alone or in combination that result in a timely, consistent, and substantial reduction of a target plant population to levels that alleviate an existing or potential impairment to the uses or functions of the water body'. This definition allows for a range of outcomes that might include weed eradication, suppression or containment, or some level of mitigation for an impact. The goals of control should always be clearly identified.

This paper summarises the outcomes of Auckland Council Technical Report 2013/026, Review of Best Management Practices for Aquatic Vegetation Control in Stormwater Ponds, Wetlands, and Lakes (deWinton et al 2013). Use of this resource may guide operational activities through to planning levels within Council. This work provides information for decision-making on the management of aquatic vegetation within the stormwater network of the Auckland region. It includes guidance on which situations require aquatic vegetation control and which management option(s) to employ. Whilst all management options are listed in this paper, the paper provides one example of the level of information included per management option, and one worked example of how to use the information.

2 ASSESSING CONTROL NEEDS

2.1 CONTEXT

In order to assess the benefits of control options for aquatic vegetation, a risk benefit analysis is recommended. Firstly, the problem should be defined before evaluating the need for control. What is the type of aquatic plant involved, where and when, and what problems are being caused to whom? As well as reactive options to problems, consideration should also be given to proactive actions to avoid the development of issues in the first place, as these are usually the most cost effective.

2.2 DEFINING ALGAL PROBLEMS

Algae are a natural component of aquatic environments that form the basis of aquatic food chains. An algae bloom, however, is rapid excessive growth of algae that can be visually conspicuous, potentially hazardous (if composed of a toxic cyanobacteria species), and/or be aesthetically unpleasant. Algae blooms that contain toxic cyanobacteria species are often referred to as hazardous algae blooms (HABs). Furthermore, when an algae bloom collapses and large amounts of algae decompose, waters may become anoxic (greatly depleted in oxygen), leading to death of aquatic plants and animals. Monitoring phytoplankton biomass and species composition is necessary to define the severity of an algae bloom and determine whether it is dominated by problematic (i.e. toxic) species.

Although stormwater management systems are unlikely to be used for recreational purposes, contact with the water is common where waterbodies are located within recreational areas (such as parks), and downstream effects should be considered. For example, blooms of toxic cyanobacteria in ponds that discharge into estuaries may result in high toxin levels in shellfish.

Public feedback over poor water clarity are received by AC Stormwater from time to time, particularly when waterbodies and their banks are green in colour, characteristic of cyanobacterial blooms, or floating algae is present (Photograph 1, including inset).

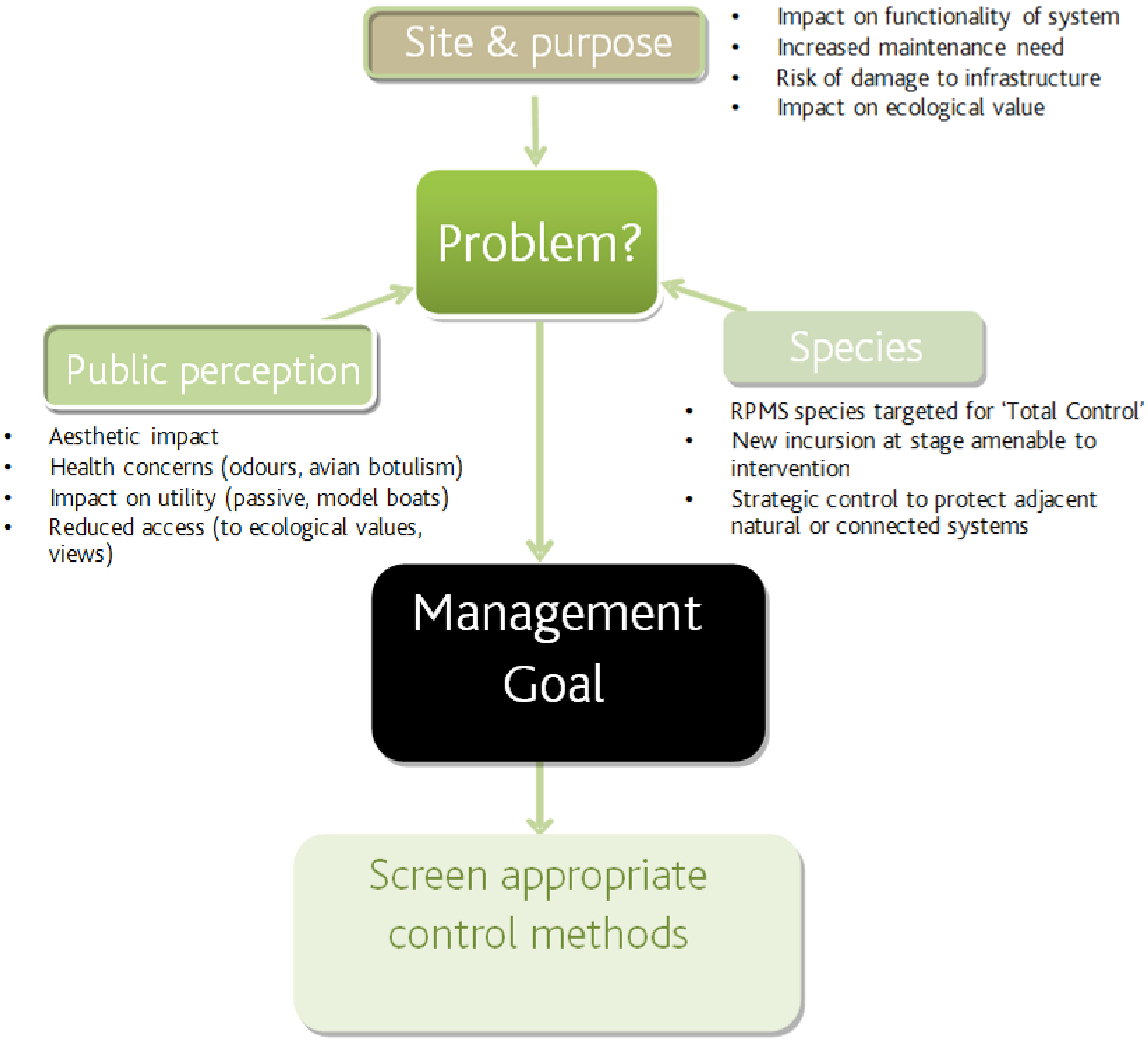
Photograph 1 Cyanobacterial bloom evident within a stormwater pond, insert of floating filamentous growths.

2.3 DEFINING PLANT PROBLEMS

A framework for establishing if there is an aquatic plant problem is provided in Figure 1. An evaluation of the problem (e.g. plant species, risk, the size of infestation) is required to identify the management goal (e.g. aquatic weed control and/or eradication) and for screening appropriate methods.

The site in question, its intended purpose and characteristics, are important to define the existence of an aquatic plant problem. For example, stormwater systems in the Auckland region include constructed wetlands, where emergent and submerged plants are utilized for their ability to retard flows and filter and process stormwater runoff to improve water quality, for bank and bed stability, and to reduce water quantity through evapotranspiration. Native plants suited to the littoral shelf and pond areas are encouraged (Auckland Regional Council 2003, Auckland Regional Council 2008, Lewis et al 2010), but some level of alien or weedy species may be acceptable, especially if similar functions are provided by the vegetation. However, the drainage and treatment of stormwater flows may be compromised by undesirable growths, such as floating sudds created by yellow flag (*Iris pseudacorus*), or dense, ramified beds of manchurian wild rice (*Zizania latifolia*). Other impacts on the functionality of wetland and pond systems might include submerged weed-beds that obstruct risers or outlets or that block debris screens, and marginal vegetation that occupies spill ways, or that damages embankments (Photograph 2). Frequently issues with aquatic plants are driven by invasive or pest species identified in the Regional Pest Management Strategy (RPMS) for the Auckland region (Auckland Regional Council 2007).

Figure 1 Main elements to defining a problem relating to aquatic plant management in stormwater systems (Auckland Council Technical Report 2013/026).



More difficult to subjectively assess are public perceptions, and impacts on aesthetic values of stormwater systems. These may include a preference for open water areas unoccupied by surface-reaching submerged plants, concerns that water 'stagnates' or litter accumulates in weed beds, opposition to the loss of water views and the importance of 'access' to nature. Public concerns for human or ecological health may be fuelled by odours from decaying plant material, or outbreaks of avian botulism in waterfowl. The link between botulism outbreaks and the need for weed management is not direct. The most effective management steps to reduce outbreaks involves the disposal of any waterfowl carcass before other birds can feed on maggots which re-cycle and concentrate the toxin (Friend and Franson 1999). Although boating, swimming and fishing are actively discouraged on most stormwater ponds and wetlands in the Auckland region, larger open ponds with good access may be utilized for model boating and some waterbodies do cater for active amenity (e.g. Lake Pupuke). Surface-reaching weed beds will be in conflict with such activities.

Goals could include the eradication of a pest species, or mitigation of the level of impact from a plant problem, or no action may be deemed necessary.

Photograph 2 Surface-reaching weeds, insert of potential blockage of pond outlet due to vegetation.

3 DECISION-MAKING FRAMEWORK

A flow-diagram (Figure 2) outlines the main steps for screening control options for an aquatic vegetation problem.

This should firstly consider what the target vegetation is (e.g. algae or higher plants, emergent or submerged plants), and then the species of problem plant. The next step is to consider the type of waterbody the problem is occurring in, the purpose of the waterbody and major characteristics, such as size and configuration. To assist in this step, a categorisation of stormwater systems is provided (Figure 3) that reflects some operational and environmental constraints on the choice of control option.

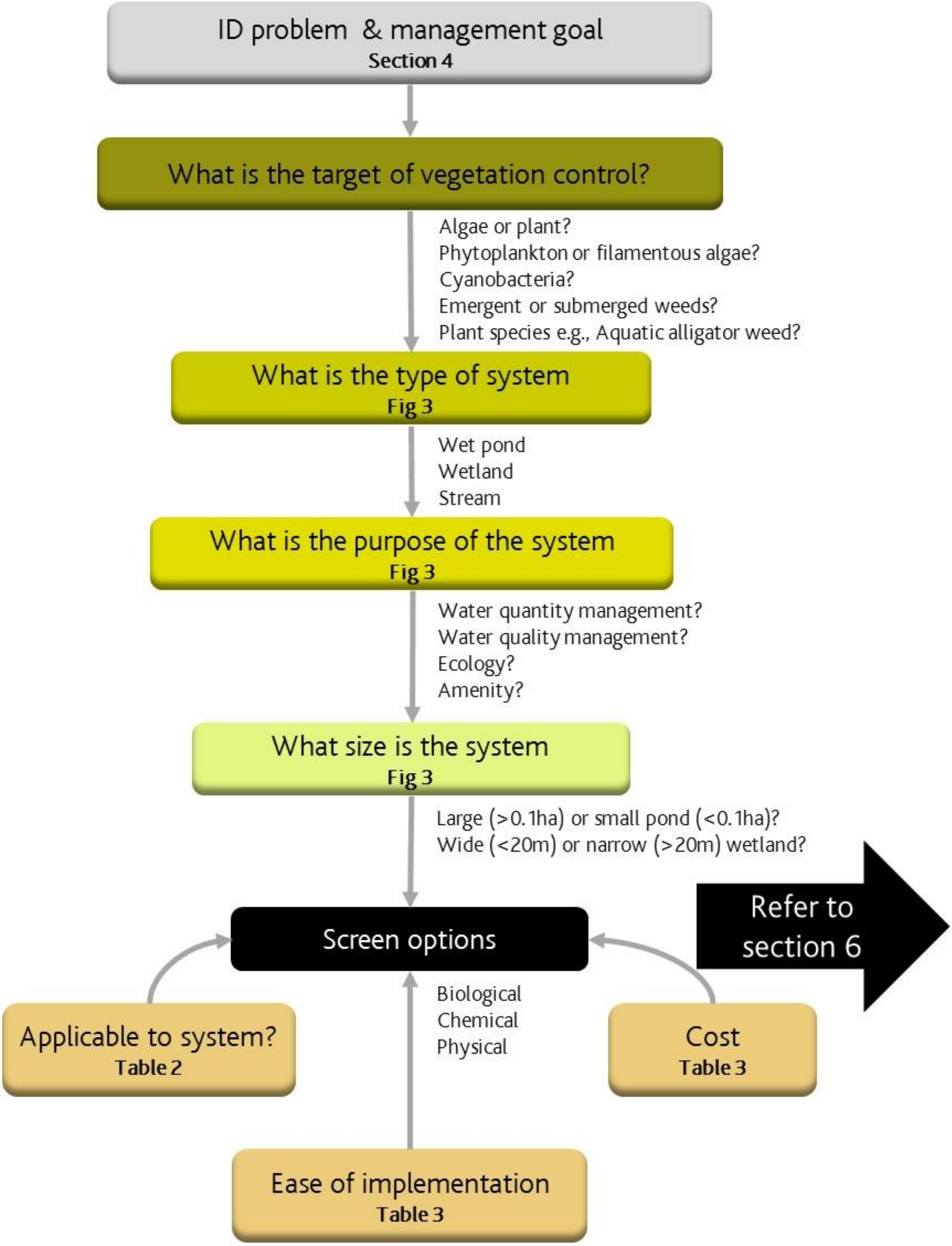
The primary purpose of stormwater systems should also be considered. From a Stormwater management perspective, the main purpose of any receiving streams is to effectively convey stormwater flows. A secondary purpose can include retention of ecological values, and amenity.

Wet ponds and wetlands for water quality and quantity management divert, retain and slowly release volumes of stormwater. Some ponds and wetlands may only perform a water treatment function. Submerged vegetation is not required for water treatment, but may be beneficial in some situations. Constructed wetlands include vegetation for the purpose of improved stormwater treatment. Ponds and wetlands may be within permanent watercourses or 'offline' (i.e. do not receive flows from, or drain to, natural streams, or only drain to ephemeral watercourses).

Methods of construction may be relevant; for instance, excavated ponds may have ground water inflows that dilute herbicides, or are less amenable to drainage and drying.

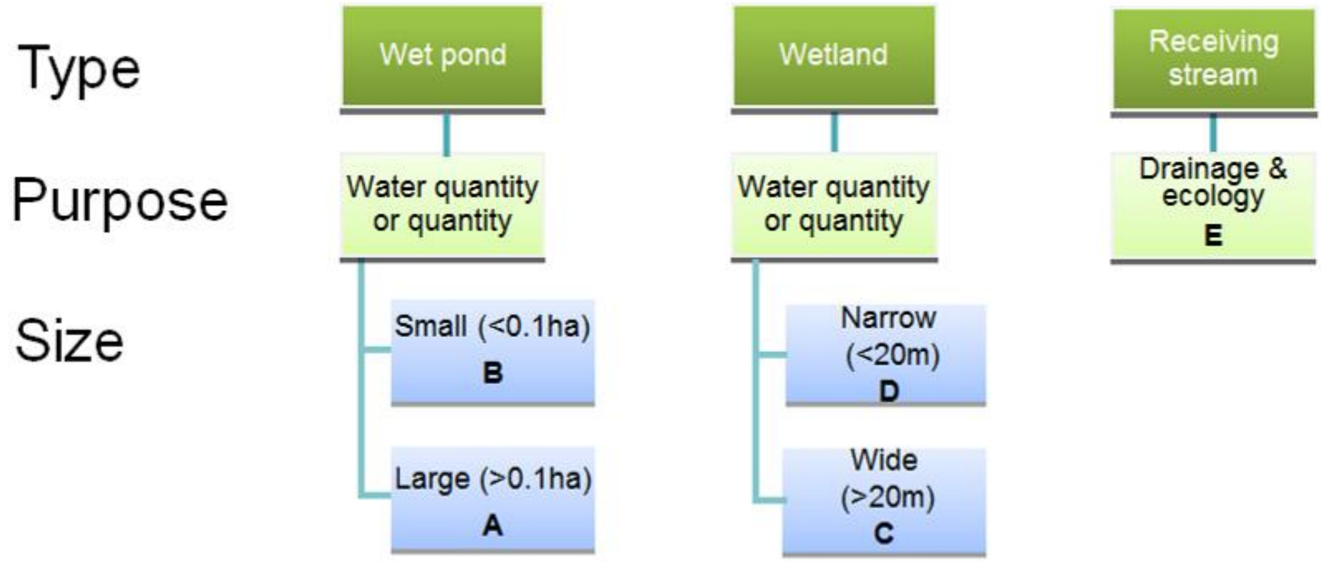
The location of the system might determine options in the case of coastal ponds that are subject to saline intrusions.

Figure 2 Steps to screen appropriate control options for aquatic vegetation management (Auckland Council Technical Report 2013/026).



Decision-making therefore requires multiple considerations, which may be a relatively complex process.

Figure 3 Categorisation of systems (A to E) relevant to identifying appropriate interventions



Thirty-five relevant management options were identified (listed in Table 1). Control options can be screened using Table 1 and 2. These reference tables should be used to shortlist possible options, with the final choice of option made in reference to more detailed option descriptions in the technical report, which provide sufficient information for individual site and species-specific considerations.

The target vegetation type for each option, and whether the option is applicable for the stormwater system in question is indicated in Table 1. Five categories of stormwater system (Figure 3) are identified, and a tick (✓) in a column indicates it is likely to be an applicable option for that system, while a cross (×) suggests it is not applicable, and a question mark (?) indicates uncertainty or the need for site or species-specific consideration. An asterisk (*) identifies those options that can be applied to parts of a system, as opposed to treatments that are likely to influence the entire aquatic system.

Other considerations for the screening of options include an indication of costs per ha, over the lifetime of the intervention (maximum of 25 years). These costs (Table 2) are indicated as Low (< $10k), Moderate ($10k to $25k), High ($25k to $50k) or Very high (> $50k). Caveats to these indicative costs are indicated in Table 2.

Lastly, an indication of the ease of implementation of the option is provided. This is not related to the likely effectiveness of an option which can vary on site and species-specific basis.

Table 1 Identification of control options and suitability for target vegetation, together with applicability to each category of system (Options that can be applied to parts of a system rather than entire aquatic system)*

Target		Option	Large wet pond	Small wet pond	Wide wetland	Narrow wetland	Receiving stream
			A	B	C	D	E
Aquatic alligator weed	Biological	Classical biological control	✓	✓	✓	✓	✓
Submerged weeds		*Mycoherbicide	?	?	?	?	?
Submerged weeds/filamentous algae		Grass carp	✓	✓	×	×	×
Cyanobacteria		Silver carp	?	?	×	×	×
Phytoplankton		Microbial products	?	?	×	×	×
Phytoplankton		Barley straw	?	✓	×	×	×
Phytoplankton		Macrophyte restoration	?	✓	×	×	×
Phytoplankton		Pest fish removal	✓	✓	?	?	×
Phytoplankton		Zooplankton or invertebrate grazers	✓	✓	?	?	×
Phytoplankton/filamentous algae		Waterfowl management	✓	✓	?	?	?
Phytoplankton/filamentous algae /submerged weeds	Chemical	Chelated copper	?	?	×	×	×
Emergent plants		* Glyphosate isopropylamine	✓	✓	✓	✓	✓
Submerged weeds		Diquat	✓	✓	×	×	×
Submerged weeds		Endothall	✓	✓	×	×	×
Emergent weeds		*Restricted herbicides	?	?	?	?	?
Terrestrial weeds		*Natural herbicides	?	?	?	?	?
Phytoplankton		Nutrient inactivation products	✓	?	×	×	?

Target		Option	Large wet pond	Small wet pond	Wide wetland	Narrow wetland	Receiving stream
			A	B	C	D	E
Phytoplankton		Flocculation	✓	✓	?	?	?
Phytoplankton/filamentous algae /submerged weeds	**Physical**	*Physical Shading	?	✓	?	?	✓
Phytoplankton/filamentous algae /submerged weeds		Shading by dyes	?	✓	×	×	×
Submerged weeds/filamentous algae		*Manual harvesting	✓	✓	✓	✓	×
Submerged weeds/filamentous algae		Mechanical harvesting	✓	?	×	×	×
Emergent/submerged weeds		*Mechanical excavation	✓	✓	✓	✓	✓
Emergent weeds		*Mowing	✓	✓	✓	✓	✓
Submerged weeds		*Bottom lining	✓	✓	✓	✓	×
Submerged weeds		*Suction dredging	✓	✓	✓	✓	✓
Submerged weeds		Water level drawdown	✓	✓	×	×	×
Phytoplankton/submerged weeds		Periodic saline intrusions	✓	✓	×	×	×
Phytoplankton (submerged weeds?)		*Substrate capping	?	✓	?	?	?
Phytoplankton (submerged weeds?)		*Sediment removal	✓	✓	?	?	?
Phytoplankton		Aeration and artificial destratification	✓	?	×	×	×
Phytoplankton		UV lights	?	?	?	?	?
Phytoplankton		Ultrasonication	?	✓	×	×	?
Phytoplankton		Wave attenuation barriers	✓	?	×	×	×
Phytoplankton		Hydraulic flushing	?	?	?	?	?

Table 2 Identification of control options and indicative costs (Low =< $10k, Moderate = $10k to $25k, High =$25k to $50k, Very high => $50k), together with an indication of the ease of implementation ([a] Costs reduced if community group involvement is possible; † Costs do not include approvals, consents, compliance monitoring, or reporting; ? Insufficient information to guide estimate).

Target		Option	Cost	Ease of implementation
Aquatic alligator weed	**Biological**	Classical biological control	Low	Easy
Submerged weeds		Mycoherbicide	†Moderate	Moderate to difficult
Submerged weeds/filamentous algae		Grass carp	†High	Moderate
Cyanobacteria		Silver carp	†High	Moderate
Phytoplankton		Microbial products	Moderate to high	Easy
Phytoplankton		Barley straw	Low	Easy
Phytoplankton		Macrophyte restoration	Moderate to high	Moderate to difficult
Phytoplankton		Pest fish removal	High	Moderate
Phytoplankton		Zooplankton or invertebrate grazers	?	Difficult
Phytoplankton/filamentous algae		Waterfowl management	Low	Easy
Phytoplankton/filamentous algae /submerged weeds	**Chemical**	Chelated copper	Moderate	Moderate
Emergent plants		Glyphosate isopropylamine	Low	Easy
Submerged weeds		Diquat	†Moderate	Moderate
Submerged weeds		Endothall	†Moderate	Moderate
Emergent weeds		Restricted herbicides	†Moderate	Moderate
Terrestrial weeds		Natural herbicides	Very high	Easy
Phytoplankton		Nutrient inactivation products	High	Difficult
Phytoplankton		Flocculation	High	Difficult

Target		Option	Cost	Ease of implementation
Phytoplankton/filamentous algae /submerged weeds	Physical	Physical Shading	Moderate to high	Easy to moderate
Phytoplankton/filamentous algae /submerged weeds		Shading by dyes	Very high	Easy
Submerged weeds/filamentous algae		Manual harvesting	[a]Moderate	Easy
Submerged weeds/filamentous algae		Mechanical harvesting	High	Easy to moderate
Emergent/submerged weeds		Mechanical excavation	Low	Easy
Emergent weeds		Mowing	Moderate	Easy
Submerged weeds		Bottom lining	High	Moderate to difficult
Submerged weeds		Suction dredging	Moderate	Moderate to difficult
Submerged weeds		Water level drawdown	Low	Easy to moderate
Phytoplankton/submerged weeds		Periodic saline intrusions	Low	Easy to moderate
Phytoplankton (submerged weeds)		Substrate capping	Moderate	Moderate
Phytoplankton (submerged weeds)		Sediment removal	High to very High	Moderate
Phytoplankton		Aeration and artificial destratification	High to very High	Moderate to difficult
Phytoplankton		UV lights	High to very High	Moderate to difficult
Phytoplankton		Ultrasonication	High	Moderate to difficult
Phytoplankton		Wave attenuation barriers	?	Moderate
Phytoplankton		Hydraulic flushing	High	Moderate to difficult

4 MANAGEMENT OPTIONS

4.1 OVERVIEW

The management options information presented in Auckland Council Technical Report 2013/026 (deWinton et al 2013) is based on publications, reports and other literature, as well as expert knowledge and authors' familiarity with emerging technologies or practices that are not yet available in the literature. Overseas information was reviewed for relevancy to the NZ situation (e.g. available registered herbicides and chemical nutrient management options). Not included were options that are unlikely to be available here now or in the near future (e.g. herbicides not registered for New Zealand use).

The purpose is to provide sufficient information to guide the specific selection of management option(s) over a range of situations. Information includes a brief description of what the option entails, the level of information available, and the likely duration of control. The applicability of the option to stormwater systems and any constraints to use are considered, as is the potential for incorporating other options in an integrated management approach. The extent of use of the control option and outcomes are briefly reviewed for New Zealand and overseas. Implementation of the option and any on-going effort are described at a generic level, as are any related practical considerations. Finally indicative costs are considered across various stages of the life-cycle of the management option (as annual or one-off costs), with an overall assessment of costs over the lifetime of the intervention, up to 25 years. Costs are indicated as Low (< $10k), Moderate ($10k to $25k), High ($25k to $50k) or Very high (> $50k).

For this paper, a single example of the management options information is given, to provide the reader with an overview of the structure and detail included in the technical report. The level of detail on any management option in Technical Report 2013/026 reflects the extent of information available and confidence level, and is intended to practical as opposed to overly scientific.

4.2 MANAGEMENT OPTION DETAILED INFORMATION - EXAMPLE: GLYPHOSATE ISOPROPYLAMINE (CHEMICAL CONTROL)

4.2.1 DESCRIPTION AND OVERVIEW

Glyphosate isopropylamine is a broad-spectrum, non-selective, systemic herbicide that works by inhibiting protein synthesis in plants. When applied to green tissue, it is translocated to growing points, including below ground organs and is effective against a wide range of plants on land or emerging from the water.

A number of marketed products have glyphosate as the active ingredient (a.i.) and these may be augmented by surfactants and adjuvants. Only products labelled for use around waterways should be used where contamination of water may occur, due to the toxicity of some types of surfactants for aquatic life. Formulations generally have 360 g per L glyphosate isopropylamine as a soluble concentrate.

4.2.2 APPLICATION - *IN WHAT SITUATIONS CAN THE OPTION BE APPLIED?*

Glyphosate should be applied to actively growing target plants and is effective against emergent and marginal plants and trees such as willows. This herbicide would be well suited to where a blanket control is required e.g. emergency spillways, embankment dams.

4.2.3 CONSTRAINTS - *IN WHAT SITUATIONS CAN THE OPTION NOT BE APPLIED?*

Glyphosate isopropylamine does not affect submerged aquatic plants and does not adequately control alligator weed, Manchurian wild rice, phragmites, purple loosestrife, sagittaria, Senegal tea or spartina. It is less effective against rhizomatous species and, as it is non-selective, it can easily damage non target plants. Effectiveness can be reduced by rainfall within a few hours of application. Efficacy is reduced in stressed plants (e.g. wilting) and where plant surfaces are dirty.

4.2.4 REQUIREMENTS - *WHAT OTHER OPTIONS / PRACTICES MIGHT BE REQUIRED IN CONJUNCTION WITH THIS OPTION?*

Mowing may be used ahead of treatment time to produce new growth more amenable to herbicide coverage and translocation. Post-treatment burning to remove dead biomass of marginal emergent plants is not advised in suburban environments.

4.2.5 TRACK RECORD - *WHERE HAS THIS OPTION BEEN SUCCESSFUL / UNSUCCESSFUL?*

In NZ has been used to manage crack (*Salix* x *fragilis*) and grey willow both aerially and via drill and inject. Effective in control of grasses (including Mercer grass, kikuyu, pampas, tall fescue, glyceria, reed canary grass, creeping bent) also sedges (e.g. rautahi), some rushes, floating species (salvinia, water hyacinth), floating leaved (water poppy, water lilies), raupo, willow weeds, water cress etc.

4.2.6 IMPLEMENTATION - *METHODS EMPLOYED*

Use of herbicides should be always be guided by label information and/or manufacturer's directions.

Glyphosate may be sprayed or wiped onto green plant surfaces, woody targets may be drilled and injected or stumps painted with the herbicide. Non-target impacts are minimised by careful application. At higher levels of application a spray mix of 8.1 g per L (or mg per kg) should be applied at the rate of 9 L of the 360g per L a.i. applied per hectare.

Application should seek to reduce environmental loads by treating before weed seed-set and spraying banks when water levels are low.

4.2.7 OPERATION, MAINTENANCE, MONITORING AND REPORTING

It takes several weeks for susceptible plants to die off, and may need follow-up where germination of plants occurs throughout the growing season e.g. willow weeds. Monitoring is required for the best timing of treatment, and to determine the period before re-treatment is required.

4.2.8 PRACTICAL CONSIDERATIONS - *E.G. SOCIAL ISSUES, ACCESS CONSTRAINTS, CONSENT REQUIREMENTS, HEALTH AND SAFETY CONCERNS*

In most instances, the use of this herbicide in these environments is not subject to resource consent requirements.

Glyphosate use is widespread in NZ. It does not bioaccumulate, biomagnify, or persist in a biologically available form in the environment and, as the mechanism of action is specific to plants, it is relatively nontoxic to animals (Solomon and Thompson 2003). In most situations glyphosate is inactivated on contact with soil and has no residual activity

4.2.9 FINANCIAL COSTS

Product costs for glyphosate are approximately $45 per ha. At an assumption of 1-2 applications per year and application costs of $100 per ha (costs variable, depending on application method), annual costs are likely to be $290 per annum.

Cost estimate per ha

(i) Start-up / implementation (once-off): Nil
(ii) Operation & maintenance (annual): Low
(iii) Monitoring: Low
(iv) Decommissioning, if relevant (once-off): NA
(v) Overall cost over the lifetime of the intervention (maximum of 25 years): Low

5 HYPOTHETICAL WORKED EXAMPLE

Online stormwater pond (0.8 hectares), within a local park, performing a treatment and detention function, discharging into the sea via a concrete pipe, limited freshwater habitat upstream, no freshwater habitat downstream, no interception with groundwater flows, no tidal inundation. The site has significant amenity values related to open water views and use. Pressure to provide a solution quickly for both amenity and to reduce flood risk. The pond has a trophic level index (TLI) >5 (poor water quality, eutrophic).

5.1 PROBLEM DEFINITION

(i) Impact on functionality of system

The pond has surface-reaching *Egeria densa*, which is reducing the water quality volume of the pond, prohibiting use of the pond for model boating enthusiasts, reducing aesthetic value (views), and is creating a flooding risk to downstream properties in heavy rainfall events due to dislodgement of weed and subsequent clogging of the pond outlet. The system is at risk of not meeting its primary stormwater conveyance function. An indirect concern may be avian botulism, which may be exacerbated due to anoxic conditions as a result of the vegetation. Amenity value offered by the pond to park visitors, a secondary function of the pond, is heavily compromised.

(ii) Increased maintenance need

Operational costs are higher due to increased monitoring (to reduce risk), more frequent inspections of the orifice to remove weed, and the implementation of an avian botulism management programme.

(iii) Risk of damage to infrastructure

The outlet has a high probability of becoming clogged in a high rainfall event, which has the potential to result in flooding of downstream properties and roads, including commercial areas.

(iv) Impact on ecological value

Upstream habitat of limited biodiversity value.

A number of complaints have been received from the public, primarily regarding amenity and recreational impacts.

Management must target *Egeria densa*. The management goal is to provide stormwater treatment, ensure conveyance is not compromised (protecting against flooding), reduce operational costs, and ensure park values for the public are maintained to a reasonable extent.

5.1.1 SCREENING CONTROL OPTIONS

The system is classified as 'A' based on Figure 3 – Wet pond, water quality, water quantity, and large (> 0.1 hectares). Table 1 is used to screen out which options are available (Table 3). Detailed management options information (as per section 4.2 above) is then used to refine this initial list of potential options. The three potential options identified through the process are then evaluated based on operation and maintenance (O&M), monitoring, reporting, practical considerations and financial costs (Table 4).

The above must be reviewed in the context of the trophic status of the pond. Pond and lake sediments accumulate nutrients (particularly phosphorus) which can be released into the water column and stimulate unicellular and filamentous algal growth. Complete elimination of all vegetation has the potential to disturb sediments, make available more nutrients in the water column, and cause the system to shift to a phytoplankton-dominated system. Whilst this would not impact on flooding, there are potential negative aesthetic and health issues associated with this.

Based on the coarse comparison in Table 4, and keeping in mind the TLI, a recommended option for weed control is as follows:

- An initial removal of most of the vegetation biomass through mechanical harvesting (weed cutting and removal), retaining weed close to the pond base; this ensures quick action can be taken.
- Stocking of grass carp at very low densities to maintain weed at low levels.
- A monitoring programme to evaluate grass carp stocking rates.
- Follow up mechanical weed harvesting (cutting) as required (infrequent).

Diquat was not included due to the risks of widespread *in situ* decay of the vegetation, resultant oxygen reduction and possible nutrient release, and the significant aesthetic impact of the weed kill. A number of other indirect weed management measures would likely also form part of an integrated approach for this stormwater pond, as follows:

- Eradication of upstream weed sources.
- Including machinery and materials hygiene in management plans.
- Planting trees on northern aspects to provide shade.

Table 3 Options available for consideration based on system classification

Target		Option	Large wet pond (A)	Further analysis
		Initial screening		
Submerged weeds		*Mycoherbicide	?	Not yet commercially available
Submerged weeds/filamentous algae		Grass carp	✓	Can be considered
Phytoplankton/filamentous algae /submerged weeds	**Chemical**	Chelated copper	?	Use would be for biosecurity emergencies only
Emergent plants	**Chemical**	* Glyphosate isopropylamine	✓	Unlikely to address submerged component of target species
Submerged weeds	**Chemical**	Diquat	✓	Can be considered, proven application for *Egeria;* unlikely to totally eradicate target species; non-toxic to fish
Submerged weeds	**Chemical**	Endothall	✓	Not effective on *Egeria*
Emergent weeds	**Chemical**	*Restricted herbicides	?	Effectiveness on *Egeria* uncertain
Phytoplankton/filamentous algae /submerged weeds	**Physical**	*Physical Shading	?	Most suitable for narrow channels and smaller sized systems
Phytoplankton/filamentous algae /submerged weeds	**Physical**	Shading by dyes	?	Unlikely option considering public perceptions
Submerged weeds/filamentous algae	**Physical**	*Manual harvesting	✓	Pond too large and deep
Submerged weeds/filamentous algae	**Physical**	Mechanical harvesting	✓	Can be considered; will not achieve total eradication as a standalone option
Emergent/submerged weeds	**Physical**	*Mechanical excavation	✓	Pond too large and deep

Initial screening				Further analysis
Target		**Option**	**Large wet pond (A)**	
Emergent weeds		*Mowing	✓	Primarily for bankside vegetation, low depth ponds
Submerged weeds		*Bottom lining	✓	Area too large
Submerged weeds		*Suction dredging	✓	Area too large
Submerged weeds		Water level drawdown	✓	Unlikely to be accepted by public

Table 4 Additional management and financial considerations for each potential option, if each is considered as a standalone option; relative ranking (1 to 6 = highest to lowest)

Option	Initial cost	O&M needs	Monitoring requirements	Reporting needs	Practical considerations	Lifecycle cost	Score	Comments
Grass carp	3	3	4	4	3	3	20	Can stock at low quantities to control regrowth
Diquat	2	2	2	2	2	2	12	Cost effective; quick results; concern over dead material and lack of pond base cover
Mechanical harvesting	4	4	3	3	4	4	22	Likely to have to be repeated annually or biennially

6 CONCLUSIONS

Identifying best practise in relation to aquatic vegetation control in stormwater systems, as outlined above, would further benefit from an adaptive approach to fine tune the use of options. This would involve monitoring of outcomes against initial management goals and good record keeping.

There is no single solution, and management decisions require consideration of multiple factors, both internal and external to the stormwater waterbody. A practical, risk averse approach is recommended.

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