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DEVELOPING HYDROGEL® FOR SELECTIVE MANAGEMENT OF SUBMERGED AQUATIC WEEDS

Nimal Chandrasena[1], Peter Harper[2] and Bill Chisholm[3]

ABSTRACT

A new technique for applying the aquatic herbicide - diquat for the control of submerged aquatics was developed in New Zealand and is now being used widely in both New Zealand and Australia. This method involves the use of guar gum, and formulating a diquat gel form (Hydrogel®), which can then be applied to water as a surface spray. The gel droplets sink rapidly on to submerged plant beds, releasing diquat at in the vicinity of target plants. This allows cost-effective 'spot treatments', targeting both containment of large infestations of an undesirable species, and eradication of small patches. Several case studies from Australia are discussed, in which diquat, used with Hydrogel®, provided cost-effective control of large infestations of submerged aquatics – hornwort (Ceratophyllum demersum), Egeria (Egeria densa), sago pondweed (Potamogeton pectinasus) and naiads (Najas tenuifolia and Najas marina) in urban wetlands, large and small lakes and a river. Recent trials in shallow ponds indicate that dense infestations Hydrilla (Hydrilla verticillata) infestations could also be reduced by approximately 50-70% with one or two treatments. However, in deeper and larger lakes, hydrilla control has been variable. In addition, Hydrogel® provides excellent control of filamentous green algal scum and submerged beds of Charophytes – Chara and Nitella at nominal costs. Results indicate that diquat residues rapidly dissipate from treated waterbodies after Hydrogel®treatments. The advantages of using Hydrogel® include reduced herbicide loads, savings in cost, increased confidence in treatment outcomes, and reduced risks of undesirable impacts on non-target species and aquatic ecosystems.

Keywords: Aquatic weeds, diquat, hydrogel.

INTRODUCTION

A number of native and introduced submerged aquatic weed species have increasingly colonized Australia's waterways, assisted mainly by human activities. The main species of concern include: *Egeria densa* Planch. (egeria), *Cabomba caroliniana* Gray (cabomba), *Hydrilla verticillata* (L. f.) Royle (hydrilla), *Ceratophyllum demersum* L. (hornwort), several pondweeds (*Potamogeton pectinasus* L.; *P. crispus*

[1]ALS Water Sciences Group, 24A, Lemko Place, Penrith, NSW 2750, Australia
[2]Bettersafe Pest & Weed Management, 33, Lagonda Drive, Ingleburn, NSW 2565, Australia
[3]Aquatic Weed Control Ltd, PO Box 11-014, Dunedin, New Zealand
Corresponding author's email: nimal.chandrasena@alsglobal.com

L. and other species), *Elodea canadensis* Michx. (elodea) and *Najas tenuifolia* R. Br. and *Najas marina* L. (naiads). Among green algae, *Chara* sp. L. and *Nitella* sp. Agardh. and several filamentous species (e.g. *Cladophora* Kutzing, *Pithophora* Whittrock, and *Spirogyra* Link) also pose problems in many nutrient-enriched waterbodies.

It is known that submerged aquatic plants mediate ecological processes in aquatic habitats, such as predator-prey interactions involving macroinvertebrates and food webs. They are also important in reducing nutrients from waterways, through luxury consumption. However, their excessive growth and biomass production often lead to adverse effects on aesthetic, recreational and economic values of waterways, and their management in waterways results in significant economic costs (Wells and Clayton, 2005).

Over the past 50 years many techniques have been used for control of submerged aquatic weeds and for local eradications, where this has been necessary. Aquatic herbicides have been at the forefront of these efforts, because they afford the opportunity to achieve the objectives effectively and cheaply in most situations, when compared with mechanical control and other methods. However, the time and method of herbicide application varies with the type of weed and the habitat in which they are to be controlled.

Diquat (Reglone®) has been used for over 40 years in New Zealand and Australia for the control of submerged species. Diquat does little harm to non-nuisance native species, such as charophytes, and native potamogetons and milfoils (Wells and Clayton 2005). Endothall (Aquathol® and Aquathol Super K®) has recently been registered for use in New Zealand, but significant restrictions remain on its use. Endothall is superior to diquat for controlling some species, such as Hydrilla (Hofstra and Clayton, 2001*,* Hofstra *et al.,* 2001*)*.

Both diquat and endothall have sound environmental profiles, and at concentrations required for control of aquatic weeds, they are relatively safe for humans, fish and other aquatic fauna. They are also not very persistent in the environment. However, when applied correctly, both chemicals have a high degree of phytotoxicity to kill aquatic weeds fast and then rapidly degrade in the water. 'Bi-Active Glyphosate', which also has a high degree of aquatic safety, is widely used for controlling a variety of emergent and floating aquatic weeds, but glyphosate is not commonly used for controlling submerged aquatics.

The mode of delivery of herbicides is very important for the effectiveness of treating submerged aquatic weeds. Various gel adjuvants have been mixed with diquat, such as alginate gum (Torpedo®), guar gum (Aquagel®) and methocel (hydroxypropyl methylcellulose, marketed as Depth Charge®). All are formulated to mix with diquat, and applied at 60 - 80 L ha $^{-1}$. When applied as a steady stream, the mixtures sink and attach onto submerged weeds and the released diquat then desiccates aquatic weeds.

The most widely used gel adjuvant is a guar gum-based product, marketed in Australia as Hydrogel®. Chemically, guar gum is a polysaccharide starch, obtained from the endosperms of seeds of a legume – Cluster Bean (*Cyamopsis tetragonoloba* (L.) Taub). The carbohydrate polymer contains galactose and mannose sugars as the structural building blocks. Food grade guar gum is used in a variety of foods as a thickener and gelling agent. It is also widely used in industry as an emulsifier, stabilizer, bonding agent, hydrocolloid, soil stabilizer and a flocculent. One of the strengths of guar gum is that it can be mixed on site to any desired viscosity. In that sense, guar gum is superior to alginate gum, as it retains a consistent viscosity at any temperature. If viscosity varies with temperature, the delivery equipment requires recalibration throughout the day (Chisholm *et al*., 2007).

The objectives of this paper are to present several case studies of using Hydrogel® to deliver underwater diquat treatments to submerged aquatic invaders in Australian waterways. These case studies demonstrate the possibilities and constraints of controlling some sensitive species, and also exemplify key factors that affect the level of aquatic weed control that can be achieved.

METHODS AND RESULTS

Diquat, mixed with the carrier Hydrogel® is applied into water from a knapsack sprayer, gun and hose, boat-mounted boom or helicopter-mounted boom. Dispersal and drift of diquat in water is significantly reduced by the gelling process, and aerial spray drift is reduced to near zero. The relatively heavy nature of the gel carrier prevents diquat from being instantly dispersed, as gel droplets sink in the water column and land on target foliage. This allows the targeting of submerged aquatic species, at specific locations in a waterway, without the need for treating the whole waterbody.

Phytotoxicity responses and control of submerged weeds were evaluated using visual observations from a boat, scooping up samples using a hook, and in other cases, with an underwater camera. Estimates of control in treated areas were expressed as percent control relative to untreated areas, four, 12 or 16-weeks after treatment (WAT).

Field Case Studies

Given below are case studies of the Diquat-Hydrogel® treatments at various locations in NSW and Queensland, targeting different submerged species. Relevant observations and management experiences are provided, and the overall results are summarised in Table-1.

Table-1. Summary of results of recent Diquat-Hydrogel® Treatments at various locations.

Location	Target Species	Treatment	% Control		
			4WAT	**12WAT**	**16WAT**
Botany Wetlands, Sydney, NSW	*Ceratophyllum demersum*	Single treatment; 600 m^2 infested area	80%	100%	100%
Del Rio Resort, Wisemans Ferry, NSW	*Ceratophyllum demersum*	Split treatment; 15000 m^2 infested area treated with a 4-week interval	50%	95-98%	98%
Georges River, Liverpool, NSW	*Egeria densa*	Single treatment; 2500 m^2 infested area	80%	98%	98%
Forest Lake, Brisbane, QLD	*Egeria densa*	Single treatment; 600 m^2 infested area	90%	100%	100%
Halcyon Waters, Gold Coast, QLD	*Potamogeton pectinatus*	Single treatment; 600 m^2 infested area	90%	100%	100%
Cable Ski Penrith, NSW	*Najas tenuifolia* *Filamentous algae*	Split treatment; 4.5 ha • 1st treatment 2.5 ha • 2nd treatment 2.0 ha	60%	95%	95%
Aqua Golf Penrith, NSW	*Najas tenuifolia*	Single treatment; 2.5 ha total area	80%	95%	95%
Port Ash	*Nitella* sp. *Najas marina*	Multiple treatments; 600 m^2 infested area	40% 60%	40% 80%	40% 80%
Penrith Lakes, NSW	*Hydrilla verticillata*	Single treatment; 2 x 1000 m^2 infested areas	>50 %	40-50%	40%
		Multiple treatments	>50 %	>50%	40%
Hyatt Coolum, Sunshine Coast, Qld	*Hydrilla verticillata*	Multiple treatments; several infested ponds; total of 2 ha treated	>50 % >65 %	40-50% >70%	40-50% >65%

Hornwort infestations, Botany Wetlands, Sydney, New South Wales

Botany Wetlands (S 33^0 56’ 01.25”; E 151^0 13’ 01.99”) are the largest freshwater lakes in the Sydney Basin. The large wetland/lake system is nationally-listed as important for migratory birds, and is recognised as regionally significant aquatic habitat. The water quality in the lakes has been poor for decades, as a result of urban runoff. Elevated concentrations of nitrogen and phosphorus resulted in recurrent, toxic Cyanobacterial blooms. The wetlands' aquatic habitat became degraded and weed infested over time, and the lakes were also invaded by the pest fish species – European Carp (*Cyprinus carpio*).

Carp are bottom-feeders, and their feeding behaviour continually disturbs lake bed sediments, leading to poor establishment of submerged aquatic plants in carp-infested lakes. However, after a sustained Carp removal program (Pinto *et al.*, 2007), a dense, almost monotypic, Hornwort (*Ceratophyllum demersum*) infestation covered the largest of the lakes – Pond 5. The density of the infestation caused a decline in all other submerged species, including both native species (e.g. *Hydrilla*) and exotic species (e.g. *Cabomba*). The change in submerged aquatic plant composition was regarded as undesirable.

The hornwort infestation was treated with a single treatment of Diquat-Hydrogel® at 30 L/ha in December 2006. Phytotoxicity was spectacular, and the dense beds collapsed within four WAT to 100% control by 16 WAT (Table-1). Water quality in the lake at the time of treatment was particularly good with low turbidity (less than 5 NTU) and average water clarity of 2.0 m. Since the treatment and control of Hornwort, the lake has developed a mix of submerged species more representative of what existed prior to treatment.

In the Mill Pond, at the downstream sections of Botany Wetlands (S 33^0 56' 18.70"; E 151^0 11' 42.98"), *Cabomba* infestations were also treated with single treatments of diquat-Hydrogel®. However, these treatments had no effect, leading to the conclusion that *Cabomba* may not be sensitive to diquat. However, being at the downstream reaches of the chain of ponds, water quality in the Mill Pond was particularly poor with very high turbidity (above 30 NTU), which may have at least partially affected the treatments.

Hornwort infestation, Del Rio Resort, Wisemans Ferry, NSW

A dense hornwort infestation in a large pond within the Del Rio Resort (S 33^0 24' 10 .92"; E 150^0 58' 02.77"), on the banks of the Hawkesbury-Nepean River in NSW, was treated with Diquat-Hydrogel® at 30 L per ha in March 2011. The treatments were conducted as split treatments, which were three weeks apart, due to the size and infestation and almost 100% cover of dense *Ceratophyllum*. The first treatment caused a near complete collapse, and the second treatment ensured that remaining fragments did not regrow. Within 8 WAT, control was 98% and the lake was almost completely clear (Table-1). Hornwort is particularly sensitive to Diquat-Hydrogel® and can therefore be very reliably controlled even with a single treatment with no known adverse effects.

Egeria infestations, Georges River, Liverpool NSW

The Georges River is a major waterway that flows through densely-populated parts of south-west Sydney. As a consequence, it is highly nutrient-enriched, due to urban growth over more than 50 years. The river suffers from serious aquatic weed infestations, including those of alligator weed, *Salvinia*, water hyacinth and submerged *Egeria*.

Once colonisation begins, *Egeria* can rapidly cover large areas of a waterway, leading to reduction in water flows. Observations in the field indicate that *Egeria* invades areas with low light availability, but is found at highest density in areas of high Secchi depth (clearer water). Dense growth of *Egeria* tends to cause laminar flow of fast moving water above the infestation, and such flows lead to undercutting of banks and increased erosion.

Diquat-Hydrogel® applications were conducted at a reach severely infested with *Egeria* (S 33^0 56′ 11.80″; E 150^0 55′ 14.90″), in January 2007. The area treated was about 2500 m^2. One treatment of 30 L Diquat-Hydrogel® completely eradicated the infestation within about two months (Table-1). Minor regrowth appeared within 12 months, possibly due to establishment of fragments from *Egeria* beds in upstream reaches of the river. At the time of treatment, the flow in the river was minimal, and conditions were calm with minimal turbulence due to wind. Turbidity in the water column was also quite low. Such conditions assist Diquat-Hydrogel® treatments, due to reduced underwater dissipation and reduced inactivation of the herbicide by suspended particles in the water column.

Egeria infestations, Forest Lake, Brisbane

Forest Lake, in north-west Brisbane (S 27^0 37′ 48″; E 152^0 57.5′ 51″) is a popular suburb that was developed about 15 years ago. The large recreational lake and cascade system of smaller lakes are key features of the development. Over the years, urban influences negatively impacted on the lakes, resulting in elevated nutrient levels, algal growth and increased aquatic plant growth, including infestations of *Egeria*, *Hydrilla* and *Vallisneria*. The excessive aquatic plant growth made some of the ponds in the system unsightly, reducing aesthetic quality, and aquatic habitat quality.

In 2009, Brisbane City Council commissioned a Trial to determine the effectiveness of Diquat-Hydrogel® to control *Egeria* at the site. The extensive, submerged beds of *Egeria* in a relatively shallow section (about 1.3 m deep) were treated with a single application of Diquat-Hydrogel® 30 L/ha on 7th May 2009. The treatments completely removed the algal scum and eradicated the *Egeria* beds within four weeks (Table-1).

Sago Pondweed infestations, Halcyon Waters, Gold Coast, Queensland

Halcyon Waters, a newly developed residential resort in the Gold Coast (S 27^0 52′ 52.41″; E 153^0 21′ 50.79″), south-east of Brisbane in Queensland, has a pond system, which is part of its water management system. Within three years, the ponds became nutrient-enriched, due to runoff from the newly developed precinct. Some ponds developed extensive beds of sago pondweed (*Potamogeton pectinasus*), covered with filamentous algal scum, causing concerns to residents. The ponds were treated with a single application of Diquat-Hydrogel® 30 L/ha in April 2009. The treatments cleared algal growth within a few days, followed by 100% control of pondweed beds within 4 WAT (Table-1). The ponds remained clear of pondweed and algae for the ensuing 12 months.

Najas and algal infestations, Aqua Golf and Cable Ski Lakes, Penrith, NSW

Large lakes of two popular, recreational resorts in Penrith, NSW were infested with *Najas tenuifolia* and filamentous algae. The lakes were treated with Diquat-Hydrogel® during the summer of 2010-11. A 2.5 ha lake at the Aqua Golf resort received a single treatment of Diquat-Hydrogel® 30 L per ha in February 2010. Diquat was quite effective on Najas, and the treated lake was cleared of *Najas* and algae within 4 WAT (Table-1).

The lake at Cable Ski received Diquat-Hydrogel® split treatments, four weeks apart, due to the large size of the water body (4.5 ha). The heaviest infestation areas (approximately 2.5 ha) were treated in November 2010, leaving the centre of the lake untreated. No adverse effects were recorded in the untreated areas, where Najas flourished until the second treatment. The lake has remained largely free of Najas for the past six months. Spot treatments ensured that other native vegetation – sporadic patches of Hydrilla and Vallisneria (*Vallisneria americana* Michx.) were left largely unaffected.

***Nitella* and *Najas marina* infestations, Port Ash Training Facility, NSW**

The Port Ash Training facility is a system of lakes, located north of Newcastle (S32 39 05.70 E 151 51 43.05). It has been designed for training for naval and seagoing vessels, using large model boats, and tidal and turbulent, flowing water conditions, representative of major sea ports of Australia. In 2009, the waterbodies became seriously infested with *Nitella* sp. in the shallower sections and *Najas marina* in the deeper sections.

Two applications of Diquat-Hydrogel® 30 L/ha, given during the summer of 2009, achieved excellent control of *Najas marina* (Table-1). However, despite initial desiccation, Nitella infestations declined only partially in some sections and were relatively unaffected in other sections (Table-1). The poor control of Nitella with Diquat-Hydrogel® could be related to high amounts of sediments and particulate matter, which coated the *Nitella* infestations.

Hydrilla infestations, Penrith Lakes

Penrith Lake, north-west of Sydney (S 33^0 43’ 27.16”; E 150^0 40’ 34.60”), is the site at which the Sydney Olympics 2000 were held. The main regatta lakes – Rowing Lake and Warm Up Lake, both have extensive beds of submerged beds of *Hydrilla* (95%). The excessive growth of *Hydrilla* has caused serious impediments for recreational water users. The minimum requirement for international competitions is clear water up to 3.5 m depth.

In Trial 1, in May 2010, selected sections of the lakes were treated with single treatments of Diquat-Hydrogel® mixture at a rate of 30 L/ha. Effectiveness was assessed by visual rating of phytotoxicity. *Hydrilla* beds were only partially affected by these treatments, and control was estimated to be 40-50%, compared with untreated control beds.

Diquat residues were also analysed as a part of the Trial with a detection limit of 0.5 µg/L (0.5 ppb). Water samples were taken at various time intervals after treatment from the water column. Diquat was detected at approximately 75-125 µg/L for up to about 1 h within the treated zones; at 6 h after treatment, the concentration was 12–32 µg/L. No diquat was detected in treated zones beyond 18 h, which indicated dissipation and dilution.

Multiple treatments, with a gap of 4-5 weeks between treatments, were applied in a second series of trials, during the summer of 2010-11. The reduction of *Hydrilla* by these treatments was also variable and ranged 40-50% at most treated locations (Table-1).

In the in relatively deep regatta lakes, the effectiveness of Diquat-Hydrogel® appeared to be influenced by several ‘site-specific factors’. The *Hydrilla* bed density and biomass was very high due to several years of ‘pruning’ by mechanical harvester (e.g. wet weight of several samples ranged from 5.4 kg to 9.8 kg per m^2). With elongated stems, comprising long stringy strands and branches, sparsely populated with leaves, the architecture of *Hydrilla* was also somewhat different from those in shallower lakes. Epiphytic, filamentous algal growth also covered the beds. Significant turbulence, due to wind and wave action caused by the boat conducting the treatments, was unavoidable. Some, or all, of these factors may have directly contributed to the reduced performance of diquat on *Hydrilla*.

Hydrilla infestations, Hyatt Regency, Coolum, Sunshine Coast, Queensland

The water levels in several ponds at Hyatt Regency, at Coolum (S 26^0 33′ 32.00″; E 153^0 05′ 33.75″), fluctuate during dry periods. Hence, the ponds are replenished with partially-treated wastewater from the Coolum Sewage Treatment Plant. The waste water enriches the ponds with nutrients, as a result of which, in 2009, extensive, submerged beds of *Hydrilla* and algal scum infested the ponds, reducing aesthetic quality. The ponds were treated with a single application of Diquat-Hydrogel® 30 L/ha in May 2009, which eradicated the algal scum and reduced *Hydrilla* beds by about 50% (Table-1). Additional treatments were given four weeks after the first treatment, reducing *Hydrilla* further.

DISCUSSION AND CONCLUSIONS

Infestations of invasive submersed plants are increasing in Australia's rivers, large and small lakes, reservoirs, tidal systems and irrigation canals. These infestations are posing serious threats to the use of waterways by blocking water movement, obstructing intakes, reducing biodiversity, and degrading habitat of threatened and endangered species.

Although the 'aquatic weed problem' is perceived as large, the solutions are relatively few. For instance, there are fewer aquatic weed control options in Australia, compared to USA or other developed countries, on account of a small population base, restricted market for herbicides or for mechanical control solutions, and legislation restricting the ability to experiment with new herbicides or bio-control agents.

Aquatic herbicides are invaluable tools, which provide cost-effective means for controlling plants submerged in water. However, presently, there are only three herbicides (e.g. diquat, glyphosate and acrolein) registered for this use, and strategies for using them effectively have not been fully developed. Ignoring this emerging problem will result in the inability to effectively respond and manage new invasive, aquatic plant infestations.

Control of submerged aquatic weeds in waterways presents particular challenges, because many are poor in water quality, which affects control, and some are used as drinking water supplies, and others for irrigation. Varying and often strong water flow patterns, turbulence caused by wind, sediment composition, changing water temperature and turbidity, and other factors can all influence the efficacy of an aquatic herbicide and the actual weed control achieved by a chemical. Treatment timing is also a key factor that influences the success of aquatic weed control with herbicides. The information available on most of the above factors is often dubious, largely due to insufficient research, and this leads to uncertainty in the minds of those who have to manage waterways.

In our view, there is a significant body of evidence from both New Zealand and Australia that the effectiveness of aquatic herbicides can be improved, to suppress extensive areas of critical aquatic weeds infestations quickly at a relatively low cost. Use of smart delivery systems, such as Hydrogel®, allows for this, particularly to accurately deliver the required dosage of diquat over a treatment area, without wasting chemicals. Diquat-Hydrogel® treatments make the control significantly more cost-effective than control by other methods. Additional advantages are that these treatments do not generate unsightly piles of aquatic weeds on shorelines, and applications require a much smaller suitable weather window, because of the speed of application and action, and the result is often long lasting. The differential response in submerged plants is at least partly related to their architecture and other mitigating factors in the field. For instance, the reduced effectiveness of diquat on *Cabomba* and *Hydrilla* could be related to less retention of the herbicide on the fan-like *Cabomba* leaves, or on the sparsely-leaved *Hydrilla* shoots.

The strength of an additive, such as Hydrogel® is that it allows spot treatments to be made targeting specific submerged infestations, without whole-lake poisoning. The spot treatments, applied using a small backpack sprayer or hand-gun can more precisely target invasive plants than do herbicide applications from hoses trailing from an airboat or from aerial applications. The use of appropriate sprayer nozzles and pressure assists the Diquat-Hydrogel® application, reducing spray drift to negligible levels, and thereby improving the selectivity of the applications with a high degree of environmental safety.

We believe that although herbicides are the most cost-effective method of aquatic weed control, there is an understandable general community aversion for using chemicals in water. This aversion can often prevent the use of herbicides over large areas. In this situation, Hydrogel® is extremely useful, because it allows less number of treatments and specific targeting, reducing herbicide loads and offsite drift. The development of new techniques for aquatic weed control needs to continue, despite the relatively small market in this field. The potential environmental impacts and monetary costs of many of the other control methods mean that more attention is needed for aquatic herbicides and smart delivery systems to achieve superior results.

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