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Goulburn Broken Catchment Management Authority

Cabomba Management

Stages 1 to 3 Report

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INFRASTRUCTURE | MINING & INDUSTRY | DEFENCE | PROPERTY & BUILDINGS | ENVIRONMENT

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1. Introduction

GHD was commissioned by the Goulburn Broken Catchment Management Authority (GBCMA) to undertake a new literature review and review of management techniques for Cabomba (*Cabomba caroliniana*). The review will provide background information for the wider Management of Cabomba project, in which trials will be undertaken to investigate management options for Cabomba in Lake Benalla, The Broken River, Lake Nagambie and associated waterbodies.

2. Cabomba Review

2.1 Cabomba Taxonomy and Biology

Cabomba (*Cabomba caroliniana* A. Gray) is a submerged aquatic plant that shares a small family (Cabombaceae) with the genus *Brasenia* (Mackey and Swarbrick 1998). It bears mainly submerged leaves, and some floating leaves (Department of Natural Resources and Environment 1999). The fan-shaped, submerged leaves (Figure 2.1) are located in an opposite arrangement along the stem (Breewel 2001) and are often covered in a thin mucilaginous coating.

Figure 2.1 Cabomba *in situ*, Casey's Weir, Victoria, showing fan-like structure of leaves, surrounded by the floating fern, Azolla

The white flower is solitary and emergent (Sainty and Jacobs 2003) and bears three sepals and three petals (Figure 2.2). Like many aquatic plants, Cabomba reproduces both sexually and vegetatively (Mackey and Swarbrick 1998), but it has, until recently, been believed that in Australia the plant does not set viable seed, despite an abundance of potential pollinators (ARMCANZ, ANZECC and Forestry Ministers 2001). However, any detached stem fragment with at least one pair of expanded leaves is believed to be capable of growing into a mature plant. In the USA, although viable seed is produced, the major growth of Cabomba is due to vegetative production (Tarver and Sanders 1977)

Recent evidence from the Northern Territory has shown that, despite earlier evidence to the contrary, Cabomba can set viable seed in Australia, as seeds and seedlings have been found near Darwin (Schooler and Julien 2006). This has been supported by the reporting of seed in Lake Benalla (B. Woolley, *pers. comm.* July 2006). Samples taken from Lake Benalla in 2007 were tested for viability and found to be unviable (Toby Grant, Benalla Rural City, *pers*. *comm*. 2007). The sample size was, however, quite small and it was concluded that the results could not be used to conclude that viable seed is not produced in Lake Benalla.

Figure 2.2 Cabomba flower and floating leaves

from http://www.nt.gov.au/nreta/wildlife/plants/ cabomba/gallery/

Cabomba is thought to prefer nutrient-rich water bodies (Oki 1994), where flow is slow to non-existent. This makes ornamental lakes and other nutrient sinks ideal for the growth of the weed, whilst suggesting that growth of Cabomba would be restricted in rivers and other fast-moving waterways, except in backwaters or slackwaters. It is believed that Cabomba may obtain nutrients from the water column, rather than sediments (Butcher 1999), again favouring growth in lakes and billabongs, where the water column can be rich in nutrients from inflows, as well as containing nutrient-rich sediments.

There is a reasonable amount of information available about the biology of Cabomba (see Mackey and Swarbrick 1998) from overseas literature, though it is still a poorly understood plant in Australian ecosystems.

2.2 Cabomba Distribution

Cabomba is native to south-eastern USA and southern Brazil, Paraguay, Uruguay and north-eastern Argentina (Mackey and Swarbrick 1998), and has also been introduced to Malaysia, India, Japan and New Guinea and been reported in China (Zhang *et al*. 2003; Bingyang 2000) and is considered a problem weed in the United States, Canada and Greece (Schooler and Julien 2006). In Australia, populations occur in the Northern Territory, Queensland, New South Wales and Victoria.

There are two known current populations of Cabomba in Victoria, both in the Goulburn-Broken catchment. A major infestation at Lake Nagambie was identified in 1996 (Gunasekera and Krake 1999) and was identified by a committee set up to develop the Lake Nagambie management strategy as one of the major weeds of concern in the lake (Goulburn-Murray Water 1999a).

Whilst some experimental work has been undertaken on Cabomba in Lake Nagambie (Goulburn-Murray Water 1999a), no formal control program for Cabomba has been undertaken in that location and the species is an established part of the vegetation in parts of the lake (Breewel 2002). Though the lake level was dropped significantly in 2000, for repair work on the weir, this timing was not utilised for Cabomba control works.

The second Victorian population is in Lake Benalla, and has been the subject of several reports into its management (Goulburn-Murray Water 1999b; Krake and Breewel 2000; Water ECOscience 2002; Lovelace 2005). This population, which was identified in 1990 (Gunasekera and Krake 1999), and its spread downstream from Lake Benalla to the weir pool of Casey's Weir has been documented in subsequent studies (GHD 2006; GHD 2007). Additionally, a farm dam near Lake Benalla was identified in 2006 as having an established population of Cabomba (Toby Grant, Benalla Rural City, *pers*. *comm*. 2007), which is likely to have been present for a number of years and survived a number of attempts to eradicate it until a second dry period in 2006-07 led to it not re-appearing in 2008.

A population was also identified in a farm dam in Gippsland (Gunasekera and Krake 1999) but has since been controlled.

2.2.1 Native Range

Cabomba is considered native to the south-eastern United States of America and southern Brazil, Paraguay, Uruguay, and north-eastern Argentina (Mackey 1996). The distribution of Cabomba suggests that it could be naturalised in the USA and originally a native of South America. There are a number of varieties of Cabomba found within this range, with *Cabomba caroliniana* var. *caroliniana* having the widest distribution.

2.2.2 Lake Benalla

Cabomba is well established in Lake Benalla. A number of smaller Cabomba control trials have been conducted on the lake (Lovelace, 2005), including herbicide trials and trials of lake drawdown.

Although drawdown has been successful in reducing the population of Cabomba in the lake, some areas of the lake are unable to be fully drained and so populations there are not exposed to the elements. An area to the north-east of Jaycee Island in the lake still supported a population of Cabomba following drawdown of the lake in 2000 (Lovelace, 2005) and was subsequently identified as supporting a healthy population of Cabomba, even in the winter period when Cabomba was dormant in the main body of the lake (GHD 2006).

By 2005, this population had grown to cover one-third of the lake and projections at the time suggested that almost 90 percent of the lake might be covered by 2008 without intervention (Lovelace, 2005), although these predictions were made prior to understanding of the biology and ecology of Cabomba in Lake Benalla.

The study into vegetation management at Lake Benalla (Krake and Breewel 2000) identified a number of control options and pointed out that control in Lake Benalla was necessary, not just to restore the lake, but also because of the possibility of the lake population spreading downstream, subsequently realised (GHD 2007).

A subsequent study (Water ECOscience, 2002) narrowed down the management options for Cabomba and recommended that lake drawdown every two to three years should be employed. The study further recommended that this drawdown should be at a time of year to expose the plants to extremes of temperature and of sufficient duration to allow complete drying of the plants. Extremes of temperature may include the frosts of winter or elevated temperatures of summer, but more satisfactory drying is likely in summer.

Dense stands of Cabomba make swimming and other water-based activities unsafe, due to the possibility of entanglement, as well as creating workplace safety issues for personnel associated with lake maintenance (ARMCANZ, ANZECC and Forestry Ministers 2001). This makes the infestation of Lake Benalla, part of a local community park reserve, particularly troublesome, as well as unattractive.

2.2.3 Broken River

Previous reports on Cabomba in the Broken River identified a small population in a backwater of the Casey's Weir pool (GHD 2006). At the time, it was considered that this population was isolated and had the potential for easy control, due to the backwater being easily isolated from the main body of the weirpool. However, the 2006 survey was undertaken in June, when Cabomba in Victoria is generally dormant, except in sheltered conditions.

A subsequent summer survey (GHD 2007) identified that Cabomba was widespread along the shallow areas adjacent to the banks of the Casey's Weir pool, a significant distance upstream from the weir. The extent of the spread of Cabomba upstream from the weir pool suggested that it was constrained to areas of slow-moving or still water, as riffle sections of the river did not support the species. It is likely that these infestations were established from propagules from Lake Benalla.

Although there are probably only a few sites in the river channel where Cabomba could establish, such as the Casey's Weir pool, being sensitive to water movement (Mackey 1996), there are many associated billabongs that provide ideal conditions for Cabomba establishment. Local residents have reported the possibility of Cabomba establishment in some of these billabongs (S. Botting, GBCMA, *pers. comm.* 2006). The turbid nature of the river associated with releases from Lake Mokoan is unlikely to be a hindrance to Cabomba growth, as it readily grows at medium to high turbidities (Mackey 1996).

Figure 2.3 Confluence of Broken and Goulburn Rivers, showing turbid water from Broken River

2.2.4 Lake Nagambie

Cabomba is a long-established part of the aquatic vegetation of Lake Nagambie (Breewel 2002), though it is currently restricted to backwaters of the lake, and is not found in the main channel of the Goulburn River that passes through the lake. Like the Broken River, it is likely that this is due to the availability of suitable habitat with slow-moving or still water.

The main area of infestation is near Picnic Point, a backwater near the northern end of the lake (Goulburn-Murray Water 1999a). This area has limited recreational value, being isolated and shallow. It also contains a major infestation of Mexican Waterlily (*Nymphaea mexicana*) with which the Cabomba appears to be closely associated (Breewel 2002).

Water from the area is pumped by one irrigator (Goulburn-Murray Water 1999a) and it is connected to the main river channel all year, due to the tightly-controlled water levels in Lake Nagambie. This opens up the possibility that propagules could move into the river and be transported downstream.

2.3 Control Techniques

Options used for management of Cabomba in the past have been restricted to drawdown of Lake Benalla and some trialling of herbicide options (Krake and Breewel 2000). In Lake Nagambie, herbicides were trialled at a time when the lake was lowered for maintenance work (Goulburn-Murray Water 1999a). No previous management work has been undertaken on Cabomba in the Broken River or its waterbodies, as Cabomba has not previously been detected in these areas.

Options for Cabomba management in waterways and waterbodies include:

- Chemical weed control, using herbicides;
- Mechanical weed control, such as cutting, suction removal and hand-pulling;
- Habitat management, such as water level manipulation and introduction of competitors;
- Shading;
- Manipulation of water quality – water aeration and water chemistry; and
- Biological control.

2.3.1 Herbicides

A number of herbicides have been used or have potential to be used for Cabomba control, though none are registered in Victoria specifically for the control of the weed. Herbicide trials for Cabomba control have been rare in Northern Victoria. In Lake Benalla, Goulburn-Murray Water conducted trials using dichlobenil and simazine (Krake and Breewel 2000) with some success, whilst they also trialled a number of herbicides at Lake Nagambie (Goulburn-Murray Water 1999a). Unfortunately, results of these trials are unavailable.

In the USA, a number of herbicides have been used for Cabomba control with varying degrees of success.

Fluridone has been shown to reduce Cabomba biomass significantly after application as an aqueous suspension (Nelson *et al*. 2002), and provide good local control *in situ* (Bugbee and White 2004), but it is not species-specific and as such also kills other species.

In addition to Fluridone, 2,4-D Amine, diquat and endothal are used for Cabomba control in the USA, with varying results (Goulburn-Murray Water 1999a).

Chemical weed control options in waterbodies are extremely limited, both through legislative controls on the use of herbicides in waterways and the public perception of environmental impacts. Whilst there are a number of herbicides used around the world for Cabomba control, the options in Australia are limited.

It is illegal to use any herbicide in a manner other than that exactly described on the label, unless a permit has been issued by the Australian Pesticides and Veterinary Medicines Authority (CRC Weed Management 2005). There are a few herbicides registered for use in aquatic situations in Australia, but the limited number of herbicides, combined with the requirement to remain below thresholds for herbicide residues (ANZECC/ARMCO, 2000), mean that detailed, professional advice should be sought before undertaking herbicide control programs.

The herbicide that has shown the most potential in recent research has been Carfentrazone. In a trial of 22 herbicides and alternative chemicals, Anderson and Vivian-Smith (2007) found that the herbicides

FMC Carfentrazone, Agricrop Rubber Vince Spray and Garlon 600 were the only three treatments that justified further investigation. They noted that Carfentrazone was of particular interest, as it already has an aquatic registration in the USA and is registered for use in rice in Australia. In their laboratory trials, Carfentrazone at 10 ppm killed 100 % of Cabomba plants.

In later field trials, conducted in Queensland (Anderson and Rogers 2007), Carfentrazone was found to provide excellent mortality of Cabomba at an application rate of around 2 ppm, which lasted for the 41-week duration of the trial. The trial noted that there may be some sensitivity to Carfentrazone amongst non-target species, including Nymphaceae species (such as the Mexican Waterlily in Lakes Benalla and Nagambie), but there was generally minimal non-target damage.

The method used by Anderson and Rogers was injection of the herbicide into the water column, rather than spraying, whilst ensuring that the herbicide is injected sideways into the water column, in order to achieve maximum contact with Cabomba foliage.

Further trials have also indicated the utility of herbicide delivery agents (Anderson 2007), with Aquacel, a commercial diatomaceous earth, and Unimin diatomite providing good dispersal patterns that could improve Carfentrazone contact with Cabomba foliage.

Studies in Queensland have found that Glyphosate has no substantial impact on Cabomba growth when applied to the water column (Toby Grant, Benalla Rural City, *pers*. *comm*. 2007). This is not uncommon amongst aquatic species, as Glyphosate is a contact herbicide. However, it may have some efficacy on plants that have been exposed by lowering of water levels. Container trials of actively growing plants were undertaken by Benalla Rural City. Water levels were lowered in the containers and the plants sprayed with Glyphosate, with results indicating complete death of plants. Field trials, that could coincide with a lake drawdown, could be undertaken to obtain further information on the efficacy of glyphosate under natural conditions.

2.3.2 Mechanical Control

Equipment for cutting and harvesting aquatic weeds in lakes is well developed and has been widely used for weed control activities around the world. Although it can be costly to hire equipment and personnel to undertake control programs, the technique provides quick removal of plant biomass and presents a clear water column in a short time.

Harvesting also removes biomass from the water, taking nutrients with it and reducing deoxygenation that may result from plant decomposition following herbicidal control. Cut weeds can be loaded onto trucks and taken from the waterbody, disposed of or mulched in a location away from any waterways, where the plant material can decompose fully without risk of spread.

However, cutting provides a short-term solution to aquatic weed infestations, acting in a similar fashion to a lawnmower. In situations of large infestation, aquatic weeds can re-grow dramatically, re-colonising areas where harvesting activities have occurred.

The tendency of Cabomba to fragment and disperse means that mechanical methods need to be employed with care. Harvesters work by cutting plants below the water line. Unfortunately, this can result in the release of plant fragments, where they are not picked up by the harvesting mechanism. Given that a small piece of Cabomba with only two leaves has the ability to grow into a new plant (Mackey and Swarbrick 1998), the release of numerous fragments is likely to have detrimental consequences for Cabomba management

Any fragments detached and released from harvesting machinery can contribute to new populations. This can be particularly troublesome in open systems, where the fragments can be released downstream.

In addition to these problems, harvesting can remove native species of flora and fauna that become trapped in the machine, as well as increase turbidity in water bodies, through disturbance of the sediments. As well as the negative environmental impacts of removing native flora and fauna, the fauna add to disposal difficulties, as, when they become trapped in the harvester, fish or other species present odour and hygiene issues at disposal sites.

Access issues also restrict harvester use. As an example, a harvester could work freely in the main body of Lake Benalla, but its usefulness would be restricted in areas of lesser access, around the upstream islands.

Suction removal is a technique used in some areas for control of aquatic weeds. It involves the complete removal of submerged plants from the substrate by means of a vacuum suction system. The technique usually involves a diver using a hose to target the species underwater, removing aquatic plants, including their root systems and detritus. Suction machines vary in size from divers operating with smaller pumps through to large machines.

The technique has been used with varying success to control the submerged weed, Lagarosiphon, in New Zealand (Clayton and Franklyn 2005) and has been used for various submerged weeds in Queensland (A. Petroeschevsky, *pers*. *comm*. September 2006). The technique has the advantage of being able to remove whole plants, including roots, without releasing fragments into the water column. It is, however, quite expensive, requiring personnel to undertake labour-intensive techniques, including diving. It is also more suitable for clearer water, where divers can easily identify the target species.

This technique has the advantage of removing fragments of aquatic weeds more effectively than cutter-harvesting, minimising the impact of vegetative propagule release and subsequent establishment of plants from these fragments.

Hand-held diver-assisted suction removal systems allow targeting of plants, where larger equipment is less discriminating. This can result in habitat impacts associated with sediment disturbance and removal of desirable species, however the technique is usually very target-specific. Suction removal equipment used in Queensland is guided by a diver and has a camera attached to allow other operators to review the process (A. Petroeschevsky, *pers*. *comm*. September 2006).

The technique is very expensive, requiring the purchase or hire of suction removal equipment, as well as personnel to undertake the dredging. Where divers are required, occupational health and safety issues can increase the cost of appointing contractors.

The technique does have advantages, in that it removes weeds without release of fragments and can be undertaken reasonably efficiently in a situation like the growth of Cabomba, where there are unlikely to be native species growing. It also has disadvantages, however, including price and habitat impacts. It also produces an immediate environment devoid of plant life, which benefits species that colonise exposed areas quickly – usually weeds. It can also have a detrimental impact on substrate structure.

For smaller populations, **hand pulling** of Cabomba may be viable, as more attention to detail with control of fragmentation can be given. However, as hand pulling of weeds can be a time-consuming and labour intensive task, this method is not viable for larger populations and could still lead to release of fragments unless due care is taken.

Hand-pulling may be undertaken on small populations when still inundated, in which case there is the potential for unseen fragments of plants to float away during the process. Alternatively, the process may be undertaken when water levels are drawn down, allowing personnel to walk across the dry lakebed to remove the plants. In this case, care must be taken not to transport plant fragments in mud on boots or clothing or to fragment plants too much with unnecessary movement across infested areas. For these reasons, for the effort that would be required and due to occupational health and safety concerns, this technique is not feasible for large populations of Cabomba, and alternatives should be considered.

Where the size of the population is suitable for hand pulling, it can be a very effective and thorough technique. Hand pulling allows the operator to target plants carefully, causing little damage to the environment around the weed and allowing for a thorough removal of fragments. It does require an understanding by the operator of the importance of hygiene and minimal impact.

In situations of heavy Cabomba infestation, hand pulling is not appropriate.

Mechanical removal of Cabomba involves techniques that are costly and require repeated activity. A number of local councils in Queensland spend in excess of $100,000 per year controlling Cabomba with mechanical measures (Schooler and Julien 2006).

2.3.3 Water Level Manipulation

The most accessible means of environmental control of aquatic weeds is manipulation of water levels. Water level manipulations have been trialled in Lake Benalla in the past (Krake and Breewel 2000) with reasonable success and have been recommended, every two to three years, for continued control in the future (Water ECOscience 2002).

Water level fluctuations have been successfully used in Louisiana to reduce Cabomba growth by up to 99 % (Manning and Sanders 1975), as well as to suppress seedling establishment and vegetative re-growth (Goldsby and Sanders 1977). It is a tool used in that state since 1945 (Richardson 1975).

Water level manipulation works with Cabomba by exposing the plants to extremes of weather. The optimal time for Cabomba control using drying is likely to be at the height of summer, when naturally high temperatures can desiccate the sediment and enable dying of exposed plants. Draining during winter may expose the plants to extremes of weather such as frosts, which commonly affect aquatic plants negatively. However, sediments are unlikely to dry to the same extent during winter as they do during summer, as rainfall events are more common, flows may be higher where the waterbody is on a river and cooler temperatures mean less evaporation. In all situations, however, longer times of exposure to extreme conditions would be preferred, within the constraints of managing the waterbody.

Despite these reservations, drawdown is a proven way of controlling aquatic plant species dependent on free-standing water (Richardson 1974), particularly at the juvenile stage (Flower, Pratley and Slater 1999). It is planned to continue as part of the management program for Cabomba in Lake Benalla in the near future.

Lake Benalla was drawn down in December 2000 and in November 2005, specifically for Cabomba control, following reports by Goulburn-Murray Water (Goulburn-Murray Water 1999b; Krake and Breewel 2000) and Water ECOScience (2002) that suggested this practice. The 2000 drawdown successfully reduced the distribution of Cabomba from extensive areas of the lake to a small arm of the lake, adjacent Jaycee Island, where it is considered that Cabomba survived, due to the inability to completely drain the area, and a sheltered situation.

The lake was drawn down in the past not just for Cabomba control, but for maintenance purposes, allowing Council to access the lake for any remedial works and cleaning and trash removal required. Prior to 1993, the lake was drawn down at the beginning of each summer, in order to clean out the public pool and filters. As Cabomba was first formally recorded in the lake in the early 1980s (Larissa Montgomery, Benalla Rural City, *pers*. *comm*. December 2008), these drawdowns, whilst not undertaken specifically for Cabomba control, would have resulted in some management of weed populations.

Following the end of annual lake drawdowns, Cabomba became recognised as a problem, due to increases in population size. However, the lake has now not been drawn down since 2005.

There are a number of negative impacts associated with draining the lake, including impacts on the ecology of the lake, movement and sourcing of water and public perception.

Lake Benalla is home to a significant population of Rakali (native Water-rats) and to Platypus, both of which have received much public attention. The fish population of Lake Benalla is, however, a relative unknown. Draining of the lake will have an impact on these species, which needs to be considered when deciding of the timing and duration of the draining event.

For example, the weir at Lake Benalla has a fishway, which is put out of service by draining the lake. This issue will be particularly critical at times of the year when fish actively migrate. Draining the lake leaves water flowing in the original channel of the Broken River, affording fish already in the lake some habitat in which to survive the draining. However, inactivation of the fishway at a time when fish migrate could have a negative impact on fish populations.

Equally, habitat for Rakali and Platypus may be removed with draining. Contingency plans for protecting native fauna in the lake should be considered.

GHD (2006) addressed some of the issues associated with drawdown and these are included in Table 2.1. This table is not to be considered exhaustive, and GHD (2006) advised that other factors may also be included in the table following further investigation. The overlap between the various factors that are included in the table already illustrates the difficulty of identifying an optimum period during which to conduct a drawdown that will still result in a positive result for Cabomba control.

Alternative arrangements for the protection of native flora and fauna species may overcome this problem to a certain extent. For example, the construction of small earthworks cotter dams around high-value assets, such as platypus breeding sites may be considered. It is difficult to be specific about the number and extent of these potential mitigation measures without a more detailed survey of lake assets, which was not included in the earlier survey of the lake (GHD 2006).

Another disadvantage of simple drainage of the lake is that parts of the lake don't drain because of the lake bathymetry, even though the main body of the lake has drained. This is particularly apparent in the case of Lake Benalla, where the channel that skirts the north-eastern side of Jaycee Island is not drained. This section of the lake was probably historically part of the inflow channel of Hollands Creek.

This is reflected, along with the particularly sheltered nature of the site, in the density of Cabomba growth that can be found in the area throughout the year. These undrained areas, supporting ongoing populations of Cabomba, can be the source of new propagules for the recently cleared areas, following re-inundation of the lake.

Because these areas do not dry out completely, Cabomba can survive in the small amount of water or saturated mud that is left, and sometimes survives under the top layers of mud (B. Woolley, Benalla Rural City, *pers. comm*. June 2006).

In these areas, it is difficult to manage Cabomba populations and some of the alternative methods discussed earlier may be the only options. In some cases, however, these areas may be able to be isolated and pumped dry. In the case of the infestation discovered behind Casey's Weir, the bulk of the population at the time of the initial survey was thought to be in a blind arm of the waterbody. The removal of Cabomba from this section of the waterbody may reduce some contribution of propagules to the main body of the weir pool, though it is acknowledged that propagules are probably being transported from Lake Benalla.

The method for isolating would be simply to close off the end of the area with earthworks, pump the area as dry as possible and leave the area for as long as possible, for the Cabomba to desiccate and die. The area could then be opened and water allowed to re-inundate the area.

This technique would be useful in areas that can be isolated due to small openings or narrow channels that can be isolated and flow made to bypass the area, such as the channel around the north-eastern side of Jaycee Island, at Lake Benalla.

The technique would involve heavy earthmoving equipment, depending on the size of the area to be isolated. Engineering and design of the earthworks barrier would need to be undertaken, to prevent failure and the associated problems of such a failure. The technique is also not applicable to all situations, and could only be used where areas can be isolated from the main body of the lake or waterway.

The accompanying issue to draining a waterbody is sourcing water to re-fill that waterbody. Where that waterbody falls within an irrigation system, as Lake Benalla does, water may need to be sourced with the cooperation of the irrigation authority. In some situations, the resources required to re-fill a waterbody may be difficult to access. Rarely, as happened on one previous occasion with Lake Benalla, could heavy rains re-fill the lake unexpectedly.

Yet another negative impact of draining the lake is public perception. In the case of Lake Benalla, it is a public asset, located in a highly visible location in public parkland. Draining a lake in that situation reduces the visual amenity of the area, presents a less attractive entrance to the town for visitors and discourages recreational use of the surrounding areas. The emptying of Victoria Park Lake in Shepparton led to significant negative public comment, though an effective public education campaign can alleviate negative perceptions.

The community of Benalla has generally accepted the need to periodically drain the lake. Therefore, additional draining of the lake is likely to be more readily accepted by the community.

Table 2.1 Example layout of calendar of important dates for uses of waterbody in which Cabomba control options are to be undertaken. (from GHD 2006)

Details of activities may not be accurate and should be confirmed. Other unforeseen activities and constraints should be added to this calendar.

(eg) 2006/07	**Month**											
Activity ↓	**July**	**August**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**Mar.**	**April**	**May**	**June**
Christmas / New Year period												
Irrigation Season (G-MW)												
Platypus breeding												
Rakali litters												
Murray Cod migration												

2.3.4 Shading

A number of trials have been undertaken using black plastic to shade Cabomba populations in Queensland (Australian Government 2008). These have included floating shade covers, which resulted in a significant reduction in Cabomba biomass in Eumundi, Queensland, and trials at a number of sites in southeast Queensland, using black builder's plastic. Additionally, black plastic was used along the edges of the Darwin River, after the application of 2,4-D Ester herbicide, to shade Cabomba, with success (Australian Government 2008).

The application of shading to Cabomba has proven successful in these trials, significantly reducing Cabomba biomass, though not eradicating the plant. However, used in conjunction with other treatments, the technique may be a useful tool in Cabomba control. For example, some sites have been revegetated with native species, following Cabomba management with shading.

Shade levels of around 99% have been shown to reduce Cabomba biomass to less than ten percent of their initial biomass within 60 days in south-east Queensland (Schooler 2008) and elimination of Cabomba in the zone between one and three metres depth was achieved within 120 days. Schooler and Julien (2006) consider this to include the optimum Cabomba depth zone.

Shading of Cabomba is labour-intensive and potentially expensive, requiring some initial work on black plastic, to make it resilient and to hold it in place. Trials in Queensland required the stitching of rope hems in the edges of the plastic to provide a robust edge, and the placement of plastic, using steel pegging.

The technique is not viable for large waterbodies, and is best suited to smaller areas, such as isolated backwaters of larger waterbodies, farm dams or, as in the Darwin River, along the edges of riverbanks. However, in these smaller areas, some of which have been identified in the vicinity of Lake Benalla, it can provide effective Cabomba management. Schooler (2008) suggests that Cabomba's lack of viable seed in much of Australia and lack of bulbs, tubers and other underground storage biomass make it susceptible to shading in these situations.

It is important, however, to combine the management with subsequent revegetation with appropriate aquatic species, as shading will impact on all plants growing in the waterbody, leading to areas that are susceptible to reinfestation.

2.3.5 Water Aeration

Aeration of waterbodies is a common method for reducing stratification of deeper waterbodies and reducing eutrophication generally. It is more commonly used to reduce the growth of blue-green algae, but there is some evidence that it may also reduce the growth of submerged aquatic macrophytes (Knud-Hansen 2007). This occurs through the oxidation of littoral limits nitrogen as ammonium in those sediments, and through the reduction of nitrogen and BOD inputs to the sediments as an eventual result of blue-green algal control.

These results are not proven, however, though an increase in oxygenation of a waterbody has direct benefits to lake ecology.

In addition to the unproven results in submerged aquatic plant control, the use of aeration equipment in waterbodies is particularly costly and may not be appropriate or possible in some areas. It is also non-specific and, if successful, would result in the loss of desirable native species, which would then need to be replaced through revegetation effort.

2.3.6 Water Chemistry

Phoslock™ is a lanthanum-modified bentonite product, which is capable of removing filterable reactive phosphorus (Haghseresht 2004) as it descends through a water column. As it settles, it forms a capping on the bottom sediment preventing any further release of FRP into the water column. It is a product that has been developed for the reduction of available phosphorus for blue-green algal growth.

Whilst no formal studies have been undertaken on the effect of Phoslock™ on submerged aquatic plants, there is some evidence of reduction in *Potamogeton* biomass as a side effect of Phoslock™ application in Western Australia (Robb *et al*. 2003), through the reduction of available phosphorus.

Phoslock™ may be a cost-effective control method for Cabomba. However, its effects on aquatic plants are relatively unknown and again it is non-specific and, if successful, would result in the loss of desirable native species, which would then need to be replaced through revegetation effort.

2.3.7 Biological Control

The development of biological control options for aquatic weeds is a long and difficult process, requiring a thorough understanding of weed biology and ecology, searching for agents in the weed's native range, extensive trial work and controlled release (Bedggood 2000). This process can take many years, without the guarantee of success at the end of the process.

In spite of the difficulties with developing biological control methods, CSIRO Entomology has had some success in identifying some organisms in Cabomba's native South America that show promise as future biological control options (Julien and Schooler 2004). The process, which began in 2003 (Schooler and Julien 2006) is expected to continue for some years, before biological control agents can be released, due to the testing and approval processes involved. Biological control will, therefore, not form a part of an initial management program in Lake Benalla or the Broken River downstream.

Two potential biological control agents have been identified, however, from the plant's native range in northern Argentina (Schooler and Julien 2008). These are a stem-boring weevil (*Hydrotimetes natans*) and a moth (*Parapoynx* spp.). Testing of the weevil for host specificity continues. The effects of both of these controlling agents may be complementary.

Despite being a valid and useful control method, the current unavailability of any control organisms for Cabomba precludes it from consideration in current Cabomba trials for Lake Benalla and the Broken River. Additionally, in Queensland the growth of Cabomba does not vary significantly throughout the year (Schooler and Julien 2006), making biological control a promising option, whereas growth in Victoria is seasonal. This results in times of the year when Cabomba populations may not be significant enough to support control organisms.

Cabomba samples from Lake Benalla have been taken and sent to CSIRO in Brisbane for genetic analysis, to ensure they are genetically similar to populations in Queensland that are being used for the development of biological control methods in Australia (Toby Grant, Benalla Rural City, *pers*. *comm*. 2007). The results of these analyses are as yet unknown, but if the samples prove to be genetically similar, the likelihood of transference of control techniques between Queensland and Victoria will be improved.

2.4 Cabomba and Weed Legislation

The importation of Cabomba is prohibited under federal legislation (ARMCANZ, ANZECC and Forestry Ministers 2001), though it is not a declared weed in South Australia or the Australian Capital Territory. It has been declared a Weed of National Significance (WoNS) in Australia and it is now banned from sale in all states and territories.

It is a declared weed in Queensland, New South Wales, Tasmania, Western Australia, the Northern Territory and, from October 2005, in Victoria, with restrictions applying in various forms in these states. The systems of classification used in each of the states are very different, so short descriptions of Cabomba status in each of the states is given below.

In Queensland, Cabomba is classified as a Class 2 weed, meaning that plants are established in the State and have, or could have, an adverse economic, environmental or social impact. Landowners must take reasonable steps to keep land free of Class 2 plants. It is an offence to keep or sell Class 2 plants without a permit (Australian Weeds Committee 2006).

In the Northern Territory, Cabomba is a Class A Noxious Weeds, meaning it has to be eradicated, and also a Class C Noxious Weeds - not to be introduced to the Territory. In this case, all Class A and B weeds are also Class C weeds (Australian Weeds Committee 2006).

In Western Australia, plant species declared in other States and Territories that are not on the Permitted and Prohibited list, are deemed unassessed and are prohibited until assessed *via* a weed risk assessment. Cabomba is currently classified as “unassessed”.

In Tasmania, Cabomba must not be imported or be allowed to be imported into the state.

There are five levels of weed declaration in Victoria (Australian Weeds Committee 2006. The categories are:

S **State Prohibited Weeds**. Do not occur in Victoria or it is reasonable to expect that they can be eradicated from the State.

P **Regionally Prohibited Weeds**. Are not widely distributed throughout the region, are capable of spreading further and it is reasonable to expect that they can be eradicated from the region.

C **Regionally Controlled Weeds**. Occur in the region, are capable of spreading further and continuing control measures are required to prevent their spread.

F **Statewide Noxious Aquatic Species**. Plants that pose a serious threat to a fishery, the aquatic environment or human health. Declared under the *Fisheries Act 1995*, it is an offence to bring these plants into Victoria or possess, sell transport or release them.

R **Restricted Weeds**. Restricted weeds are plants that may occur in Victoria. They are weeds that have the potential to spread into and within Victoria, and pose an unacceptable risk of spreading in this State or to other parts of Australia if they were to be sold or traded in Victoria. Cabomba is in the Category.

2.5 Potential Impacts of Cabomba

A number of impacts of Cabomba proliferation have been identified. These fall broadly into the categories of social, economic and environmental impacts, though there can be overlap between these categories. For example, reduction in recreational opportunities is a social impact, but can also contribute to an economic impact.

2.5.1 Social impacts

- **Drowning hazard**. Swimmers and other recreational users of the lake may become entangled in Cabomba infestations, which grow in long, intertwined masses. This is particularly dangerous to young children, either swimming in the area or who may fall into the water and become entangled in the plant mass.
- **Recreational restriction**. As well as administrative restrictions that may be imposed to prevent use of waterways infested with Cabomba (bans on swimming, fishing), the presence of Cabomba in a waterway can restrict recreation in itself. Swimmers that encounter Cabomba are less likely to swim in the area, anglers are less likely to want to use the area for fear of tangling lines and other users may also be less inclined to use areas for recreation.
- **Aesthetic**: visual and smell. Dense infestations may be considered unattractive to those using the area for passive recreation, such as walking or picnicking by a waterbody. In addition to the visual aspect, often-dense infestations of aquatic weeds result in musty, anoxic or otherwise unpleasant odours.
- **Fishing.** Anglers are disadvantaged by dense infestations of weeds like Cabomba, as plant material becomes entangled in lines and makes it physically difficult to fish in the area. In addition to these difficulties, the presence of dense infestations of exotic weeds often reduces available habitat for native fish, reducing the success rate of anglers. Again, restrictions on fishing may also be applied, further impacting on anglers
- **Need for education – management, control spread**. Education is an important aspect of management for an invasive weed, particularly in areas of high interaction between the community and the area of invasion. It is important that the community understand the impacts of the weed and the actions that they can undertake to ensure they do not contribute to the spread and that the community is supportive and understanding of the measures being undertaken by the responsible authority to control the weed. In the case of Lake Benalla, previous drawdowns of the lake have necessitated an effective communication strategy to educate the community on the reasons behind the action taken.
- **Heritage values**. These values can be difficult to quantify, however can be impacted by weed growth. They may include the waterbody itself, which could be considered a heritage asset, or its place in the heritage environs of the area, but can also include smaller assets within the waterbody.

  Indigenous heritage values may also be impacted by weed infestation, including degradation of heritage sites and reduction in accessibility to areas due to weed growth.
- **Cultural impacts**. These impacts can range from impacts on the use of the area for cultural events and activities to impacts associated with inability to extract water.

2.5.2 Economic impacts

- **Management of flows – irrigation supply**. Lake Benalla and the Broken River are integral parts of the irrigation system in the area. Lake Benalla's role in irrigation flows is also likely to increase as Lake Mokoan is decommissioned. Equally, Lake Nagambie is an integral part of the irrigation infrastructure of not just the Shepparton Irrigation Region, but also, through its connection with Waranga Basin, irrigation and water supply systems further west. The presence of dense infestations of Cabomba in these carrier systems can impact directly on the efficiency of water movement and lead to spread of Cabomba through irrigation infrastructure. Control methods based on system drainage may also impact on irrigation supply and require careful planning with respect to irrigation demands.

- **Stock and domestic supply**. These supplies may be impacted by difficulties associated with extracting water from areas where Cabomba is growing, such as filtration costs or the inability to extract water due to the presence of weeds. Costs include loss of production or access as well as increased costs to ensure access.
- **Costs for management and monitoring – obvious and hidden costs**. There are a number of recommendations in this report for the management of Cabomba in Lake Benalla and the Broken River. All of these options will cost money to implement and a number of issues will need to be addressed in order to properly implement control options. These issues increase the capital cost of the work.
- **Education costs**. Education and awareness programs, like those mentioned above, incur costs to the responsible authority.
- **Potential infrastructure modification**. In some cases, infrastructure may need to be modified to continue being used when an infestation of a submerged aquatic weed occurs. For instance, filtration costs of water used by diverters may increase and modifications to filtration equipment may be necessary. In extreme cases, it may be necessary to modify infrastructure to draw water from a different area or different source.
- **Agency coordination cost and in-kind support**. Coordinating management programs and the agencies responsible for implementing programs brings costs to the agencies and to those coordinating the program. These costs can be direct or can be met by in-kind support from agencies.
- **Tourism – loss of revenue**. Dense infestations of aquatic plants, as outlined above, decrease the aesthetic appeal of an area and reduce recreational activities. Where these activities contribute to the regional economy, a decrease in waterbody use can impact negatively on spending.
- **Potential spread to irrigation areas and natural wetlands**. If infestations spread to new areas, control costs increase with the spread. The costs involved if the weed spreads to irrigation areas can include control costs for irrigation authorities, as well as reduction in irrigation infrastructure efficiency and increases in pumping costs.
- **Farm dam costs**. Control by individual landholders in farm dams also incurs costs to the landholders, such as herbicide costs or costs of draining and refilling dams.

2.5.3 Environmental impacts

- **Reduction in habitat and biodiversity – Flora and Fauna, EPBC species**. Dense infestations of submerged exotics, such as Cabomba, are rarely utilised by native species. Species such as Rakali (Water rat – *Hydromys chrysogaster*) and Platypus have burrows hidden in riverbanks. The use of these burrows may be compromised by the presence of dense aquatic weed infestations. Platypus is a listed species under the Environment Protection and Biodiversity Conservation Act 1999.

  Native aquatic plant species are disadvantaged by the competitive advantage of Cabomba growth, which completely covers areas of habitat and excludes other plant species.
- **Water quality, dissolved oxygen, fish deaths**. Dense infestations of aquatic weeds are often associated with decreases in dissolved oxygen and increased sedimentation, which impacts on water

quality. Low levels of oxygen are detrimental to fish health and, in extreme cases, can lead to fish deaths.

» **Fish passage interruption**. Where fishways are installed on structures or waterways are narrow, dense infestations of Cabomba can interrupt the passage available for fish migration.

» **Flow restriction**. Like all aquatic weeds, dense infestations of Cabomba may restrict flow in waterways. Where large flows can move through clear channels, the same volume of water attempting to move through an infested channel can lead to bank overtopping and flooding.

2.6 Potential for Cabomba Spread

There are a number of routes through which Cabomba could spread through the Broken River system. The two main routes are down the Broken River itself and through the Broken Creek. Both of these routes could potentially lead to infestation of irrigation systems and eventually to the potential for infestation in the River Murray.

2.6.1 Broken River – Goulburn River – River Murray

Though the possibility of Cabomba colonising areas of fast-moving water is limited, the Broken River downstream of Lake Benalla is impounded twice (Casey's Weir and Gowangardie Weir) and also is associated with a number of off-stream wetlands. Establishment of Cabomba in either of these impoundments or through flooding of wetlands enables the plant to establish a population that can then expand and provide propagules to colonise further down a river. Established principles of aquatic weed infestation (Arthington and Mitchell 1986) suggest that proliferation of weeds is a staged process of invasion, establishment and dispersal. The establishment of populations in wetlands and impoundments leads to a population large enough to produce sufficient propagules to disperse and establish downstream.

In this way, the wetlands and impoundments of the Broken River may allow Cabomba to establish and disperse, then spread out through irrigation infrastructure onto irrigated farms and then spread further or allow it to reach the Goulburn River and through the same processes the River Murray.

The risk of spread is particularly high in flood events.

2.6.2 Broken River – Broken Creek – River Murray

Just as Cabomba could spread down the Broken River system to irrigation areas or eventually to the River Murray, so it may also spread in the Broken Creek system. The Broken Creek arises from the Broken River, upstream of Casey's Weir, and moves across northern Victoria, before draining into the River Murray at Barmah.

As well as the natural waterways of the Broken Creek system, such as Boosey and Nine Mile Creeks, the system contains a number of impoundments and is an integral part of the irrigation system of the area. Like the Broken River, impoundments may allow Cabomba to establish and disperse, whilst the network of irrigation infrastructure may allow Cabomba to enter irrigation systems (channels and drains).

The system may also lead to Cabomba moving into the River Murray.

2.6.3 Lake Nagambie – Goulburn River/Goulburn Weir irrigation channels – River Murray

Just as Cabomba could spread down the Broken River system to irrigation areas or eventually to the River Murray, so it may also spread through the Goulburn system, either through being transported downstream in the Goulburn River, or by moving through irrigation transport systems, such as the East Goulburn Main Channel.

Movement of Cabomba propagules in the Goulburn River could eventually lead to infestation in the River Murray, whilst movement in irrigation infrastructure would lead to a dissemination of propagules across a large area, into smaller channel systems, farm infrastructure and, in particular conditions, through drainage infrastructure and back into natural waterways.

3. Trial Options

The following is a summary of trial options which could be considered. It is difficult to rank the possibility of success of these trial options, as similar trials have been undertaken in environments, such as the Northern Territory, that are very different to that in Lake Benalla. However, undertaking the trials will provide direction and ranking as to the most effective means of Cabomba management in this environment in the future.

Herbicides

A number of herbicides have been tested for the control of Cabomba. Of most promise is Carfentrazone, which has been successfully trialled in northern Australia. If an off-label permit can be gained for the use of Carfentrazone in trials in northern Victoria, it may be a promising tool for management. Herbicide trials, particularly of Carfentrazone, undertaken in Victoria would add value to the results of trials already conducted in Queensland.

Glyphosate trials, undertaken in conjunction with drawdown, would indicate the efficacy of this herbicide under these specific conditions. Glyphosate has the advantage of being a relatively inexpensive herbicide option and a chemical that is considered relatively 'safe' to use, when compared to other more volatile chemicals.

Mechanical Control

Mechanical control is an expensive method of submerged aquatic plant management. Additionally, it generally provides only temporary control of aquatic plants and, unless carefully undertaken, can result in the release of propagules. There are, however, a number of methods of mechanical control. Suction dredging is not recommended, as it significantly disturbs sediments, whilst the use of cutter boats may not be appropriate for smaller areas. Small infestations that are yet to spread may respond well to hand removal. Though labour-intensive, hand removal may be worth trialling in smaller areas.

Water level manipulation

Water level manipulation has been used successfully at Lake Benalla, where a number of lake drawdowns have resulted in significant reductions in Cabomba infestations. Although drawdowns result in a temporary reduction in the extent of Cabomba, used in conjunction with other techniques, water level manipulation continues to be a viable tool in Cabomba management and should be included in further trials.

In conjunction with, or independently of, a large-scale drawdown of Lake Benalla, the opportunity could be taken to draw down discrete or isolated parts of the lake, such as the Holland Creek arm running to the north of Jaycee Island. This could be undertaken through the construction of earthen dams to isolate the section and then pumping out of the water in the section, taking care to dispose of the pumped water in a safe area where Cabomba is unlikely to re-establish from fragments.

Drawdown can also be used in conjunction with trials on herbicides, such as Glyphosate.

Shading

Shading is labour-intensive, can be expensive, and is not practical for large areas. However, for Cabomba management in small waterbodies, such as farm dams or isolated sections of larger waterbodies, shading is a viable and effective technique and should be included in further trials. Results of trials from Queensland (Schooler 2008) have shown particularly promising results for shading as a management tool for Cabomba.

Water aeration

Water aeration involves the installation of complex and expensive infrastructure and the advantages of the technique for management of submerged aquatic vegetation have not been firmly established. It is unlikely that this would be a viable technique to pursue in trials of Cabomba management.

Water chemistry

The advantages of water chemistry manipulation technique for management of submerged aquatic vegetation have not been firmly established, though a reduction in available nutrients for plant growth should result in a reduction in nuisance growth. However, the application of a product, such as Phoslock™, in smaller areas, such as farm dams or isolated sections of larger waterbodies would not be expensive to trial.

Biological control

Research into biological control of Cabomba in Australian systems continues and final results are not yet available. However, cooperation with researchers in the area of Cabomba biological control may provide useful links that would be beneficial to trials in Victoria and in providing further information to research efforts in other states.

4. Conclusion

There are a number of potential techniques that could be trialled for Cabomba control in Lake Benalla, Casey's weir, Lake Nagambie and smaller waterbodies, such as farm dams. Some of the potential techniques, such as shading with black plastic are better suited to smaller situations, and suitable areas should be identified for undertaking trials of these methods.

It is important to test as many potential methods of Cabomba control as possible, in order to build a repertoire of techniques to integrate into a management regime. Integrated weed management (IWM) can be defined as the integration of effective, environmentally safe and socially acceptable control tactics that achieve the desired level of control (Elmore 1996). Successful trials in Queensland of the techniques outlined in this report indicate that such an approach could be implemented for Cabomba in Northern Victoria.

Trials in the Goulburn Broken Catchment would add significantly to the results achieved in Queensland and help in the development of a nationwide approach to Cabomba management that takes into account local conditions and suitable techniques. Cabomba trials are being undertaken in a number of states, including shading work in Northern Territory and Queensland (Schooler 2008), biological control investigations (Schooler and Julien 2008), and trials of drawdown and shading in New South Wales (David Officer, NSW Department of Primary Industries, *pers*. *comm*. October 2008). It is important for Cabomba researchers in the Goulburn Valley to maintain contact with other states and share knowledge on Cabomba control and management techniques that arise from these and other trials.

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