Risks and Benefits Associated with using Compost Prepared from Harvested Aquatic Weed for Improving Land Condition

Department of Environment & Climate Change NSW

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EXECUTIVE SUMMARY

Background

A collaborative research project was undertaken by the NSW Department of Primary Industries, the Department of Environment and Climate Change (DECC) and Hawkesbury-Nepean Catchment Management Authority, to: 1) assess the risks associated with applying compost prepared from aquatic weeds (AWC) to land; and 2) evaluate the benefits of using AWC in catchment rehabilitation works.

Environmental Risk Assessment

Consultation with stakeholders at the beginning of the project identified four key risks associated with applying AWC to land, namely: survival and spread of weeds, particularly Alligator weed (*Alternanthera philoxeroides*), which can grow in aquatic and terrestrial environments; eutrophication of waterways; accumulation of heavy metals in the environment; and phyto-toxicity. These risks were assessed by validating the composting process performed by a commercial compost producer (BetterGrow Pty. Ltd) at the Hawkesbury City Council Waste Management Facility, near Windsor, NSW. This included monitoring the temperatures at different depths within the composting windrow over time to determine if critical temperatures were achieved and assessing the site for signs of viable alligator weed. In addition, composite samples of AWC were collected at the conclusion of composting and analysed for a range of chemical, physical and biological characteristics, following the procedures outlined by Standards Australia (2003). Experimental work was also undertaken to examine the effect of composting on the survival of alligator weed, compared to untreated control plants.

The potential for aquatic and terrestrial weeds, particularly Alligator weed, to survive the composting process was the main risk identified. Experimentation revealed composting is an effective method of reducing the viability of aquatic and terrestrial weeds. However, weed mortality depends on the temperature within the composting windrows and the length of time the material is subjected to the composting process. Consequently, the composting process must be carried out in accordance with the Australian Standard for composts, mulches and soil conditioners (AS4454) in order to be effective.

Site monitoring revealed some alligator weed growing at the base of the compost windrows and elsewhere on the site. This was attributed to the lack of an appropriate hardstand upon which the compost windrow was established. This meant that not all of the material in the windrow was turned and exposed to the pasteurising conditions (>55^{o}C for three consecutive days) required to destroy any viable weed seeds or plant fragments.

Using Alligator Weed as an indicator organism, it is therefore likely that harvested aquatic weed, which was not subjected to thermophilic (>45^{o}C) or pasteurising conditions, could contain viable fragments of terrestrial and aquatic weeds. This would have major consequences with respect to water quality and riparian ecology if this material was applied to areas of the Hawkesbury-Nepean Catchment where Alligator Weed does not occur. Therefore, the overall environmental risk of aquatic and terrestrial weeds surviving the composting process and spreading is high and requires on-going management.

Erosion control performance

A rainfall simulator was used to measure the ability of AWC to reduce runoff and erosion from experimental plots in comparison to a bare earth control and other commercially produced composts and soil conditioners. A 1 in 10 year rainfall event (67 mm/hr) was applied to the plots for 30 min using a rainfall simulator. Runoff was captured, volume was recorded and water quality samples were collected and analysed for a number of parameters including the concentration of nutrients and total suspended sediments (TSS). Sediment

export rates (kg/ha) were calculated by multiplying the area of the runoff plots (m^2) by TSS concentration (mg/L) and runoff volume (L). Treatment effects on vegetation production and ground cover were assessed 6 and 12 weeks after the rainfall simulations were completed.

The application of compost prepared from harvested aquatic weed (AWC) significantly reduced the export of suspended solids from the plots, relative to the bare earth control by 34%. However, it was less effective than the other compost treatments evaluated. This is because the AWC only contained a small proportion (5.5%) of particles >15 mm in size which physically shield the soil surface and help trap entrained soil particles. Pasture dry matter production and ground cover in the runoff plots was significantly increased by AWC application. This indicates it would be a good medium for pasture establishment, particularly in soils denuded of topsoil. Moreover, applying AWC at a depth of 20 mm supplied an equivalent of 699 and 95 kg N and P/ha, respectively. Over time this should mineralise and provide some benefits with respect to soil fertility and plant nutrition.

<u>Conclusions and recommendations</u>

Composting is an effective method of converting aquatic weeds extracted from waterways, into a product which can be beneficially reused to reduce erosion and act as a medium for promoting vegetation establishment in degraded catchments. The main environmental risks relate to the spread and survival of weeds which can grow in aquatic and terrestrial environments (eg. alligator weed). However, a properly managed composting process (ie. complying with AS4454) should minimise this risk. If composting is selected as the preferred method for managing organic material harvested from waterways, then on-going monitoring and evaluation is required to validate the process and ensure confidence in the final product.

<u>Outcomes and deliverables</u>

The outcomes from this project are 70,000 m^3 of organic material diverted from landfill; 2,000 m^3 of composted soil conditioner produced for beneficial reuse and a further 2,000 m^3 currently being produced; Improved understanding of the risks and benefits associated with compost prepared from harvested aquatic weed; and recommendations for managing the risks associated with compost prepared from harvested aquatic weeds.

The deliverables from the project include 1 project report, 1 field day, 4 education and extension publications and 1 conference paper. Two manuscripts are currently being prepared for submission and publication in peer-reviewed scientific journals.

1 INTRODUCTION

1.1 Background

A large infestation of Salvinia (*Salvinia molesta*) occurred in 2004 on the Hawkesbury-Nepean River. Approximately 70,000 m^3 were harvested as part of an aquatic weed control project managed by the NSW Department of Primary Industries. The preferred option for managing this harvested material was to compost it at a commercial composting facility. However, options for its ultimate end use need to be identified, given the Sydney urban landscaping market is already saturated with composted products.

One option is to use the compost derived from aquatic weeds to increase ground cover, reduce runoff and minimise soil erosion in degraded areas of the Hawkesbury-Nepean Catchment. This option is advantageous in that it creates an opportunity to beneficially reuse the harvested aquatic weeds in areas of the catchment affected by soil erosion. Reducing sediment transport from degraded sites and agricultural land in the upper and lower catchment can help reduce nutrient accumulation in waterways. Reducing the overall nutrient accumulation in waterways will lead to a decrease in the incidence of aquatic weed outbreaks, particularly in times of drought.

However, the ability of these materials to control surface runoff and sediment transport needs to be evaluated to ensure it can be safely used in the field. Further, it is necessary to perform an environmental risk assessment to ensure the compost does not spread aquatic and terrestrial weeds or other contaminants in the catchment.

The objectives of this project are to conduct a risk assessment and evaluate the erosion control performance of compost derived from harvested aquatic weed.

1.2 Land degradation in the Hawkesbury-Nepean Catchment and effects on water quality

The Hawkesbury-Nepean catchment covers 21,400 square kilometres and supplies most of the reticulated water for Sydney’s 4.13 million inhabitants (HNCMA 2005). It is an area of state and national significance and is important from many historical, social, economic and environmental perspectives. For example, it includes much of the Greater Blue Mountains World Heritage Area and contains many species of flora and fauna which are of conservation significance (HNCMA 2005). Agricultural production in the catchment is worth more than one billion dollars annually and supplies much of Sydney’s fresh vegetables, flowers, and fruit (Gillespie and Mason 2003). It is also the site of first European settlement in Australia and surrounds Australia’s largest city, Sydney.

Competing land uses and demands for water have reduced environmental flows, which, combined with drought conditions, have lead to extensive and repeated aquatic weed outbreaks in the main stem of the Hawkesbury-Nepean River in recent years (HNCMA 2005). Likewise, land degradation in the catchment and soil erosion arising from it has reduced downstream water quality. For example, it is estimated that approximately 11% of the Sydney Catchment is affected by high or very high sheet and rill erosion (Department of Environment and Climate Change, 2005). Consequently, the Hawkesbury Nepean Catchment Management Authority has set specific targets to improve soil and land condition in the catchment. For example, it aims to reduce the area of land severely affected by erosion by 15% (30 000 ha) by 2016 through its Catchment Protection Scheme (HNCMA 2005).

1.3 Aquatic weeds

Aquatic plants are often deliberately introduced into a country for use as ornamental plants in aquariums and fish ponds. However, they can escape into the surrounding environment and have a devastating effect on water quality. Aquatic weeds can bring rivers and lakes to a standstill, destroying their ecology and also the livelihoods of communities who depend on them.

There are a number of aquatic weeds which have become established in waterways throughout Australia. Three significant aquatic weeds in the Hawkesbury-Nepean Catchment are Salvinia *(Salvinia molesta*), *Egeria densa* and Alligator Weed (*Alternanthera philoxeroides*).

1.3.1 Salvinia (*Salvinia molesta*)

Salvinia is regarded as one of the worst weeds in Australia because of its invasiveness, rapid spread, economic and environmental impacts. The plant has been declared as a weed of national significance and a noxious weed (NSW Agriculture, 1993).

Salvinia originated from southern Brazil but became popular for use in aquariums and fish ponds and has subsequently spread throughout the world. The plant was first recorded as weed in Australia in 1952 near Sydney and shortly afterwards near Brisbane in 1953 (van Oosterhout 2005). Since this time, it has been recorded in most east coast river systems from Cairns in far-north Queensland to Moruya on the south coast of New South Wales (Figure 1). It has spread from backyards to urban waterways in all capital cities, whilst remote infestations have also been recorded in the Top End of the Northern Territory and regions of Western Australia (CRC Weed Management 2003).

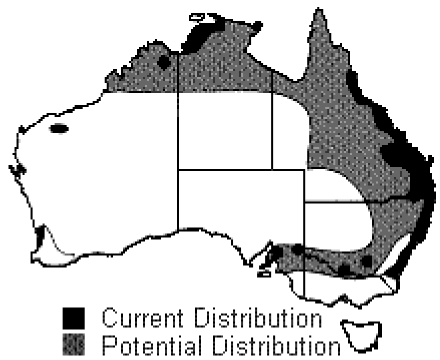

Figure 1. Current and potential distribution of Salvinia in Australia (Sainty and Associates 2001).

Salvinia belongs to the *Salviniaceae* family and is a free-floating, mat forming perennial aquatic fern which has slender stems and floating leaves. The leaves of Salvinia are paired and are round to oval in shape, with dense waxy hairs on the upper surface. The shape and size of the leaves depends upon the age of the plant and the degree of crowding. The stems are submerged, green, branched and covered in fine hairs. Axillary buds are located along the stem at each node (Ensbey 2000). In Australia, Salvinia reproduces by fragmentation rather than sexual reproduction.

Salvinia has the ability double its size every 2-3 days and exhibits rapid growth in water with high nutrient concentrations (CRC Weed Management 2003). Salvinia forms dense mats (Figure 2) that can cover entire water bodies, these mats severely interfere with the use of water bodies for recreational activities and irrigation. The mats can shade out submerged plant life and impede oxygen exchange, making the water unsuitable for fish and other organisms leading to significant impacts on catchment biodiversity (Douglas-Oliver 1993).

Salvinia is very difficult to manage given there is no totally effective control technique available. Mechanical control is achieved through the use of floating booms to help contain infestations and restrict the spread of the plant. These barriers, in conjunction with mechanical removal and chemical control, help dramatically reduce infestations. However, care needs to be taken, as fragments can break away and cause new infestations downstream. As such, regular monitoring and follow up work is required.

Figure 2. Illustration of the mats of Salvinia which form on the water surface (CSIRO 2005).

Biological control is playing an increasingly important role in controlling Salvinia infestations throughout Australia. The Salvinia weevil (*Cyrtobagous salviniae*) originated in Brazil and was introduced into Australia by the CSIRO in (Figure 3) (CSIRO 2005). The Salvinia weevil has been less effective as a biological control agent in regions south of Grafton, NSW due to cooler climates and shorter growing seasons in these areas (Ensbey 2000).

A combination of chemical, mechanical and biological control methods have been used to dramatically reduce the population of Salvinia in some areas, although regular monitoring and on-going management is required to bring the weed under control.

Figure 3. Illustration of the Salvinia Weevil (*Cyrtobagous salviniae*) used in the biological control of Salvinia (CSIRO 2005).

1.3.2 Alligator Weed (*Alternanthera philoxeroides*)

Alligator Weed is regarded as one of the worst aquatic weed threats in Australia and has been declared as a weed of national significance and a noxious weed as defined in the Noxious Weeds Act 1993. The plant has adapted to grow in both aquatic and terrestrial environments (Parsons and Cuthbertson 1992). The plant was introduced from South America into Newcastle, Australia in the 1940s and has subsequently spread to all states (Sainty *et al.*, 1998).

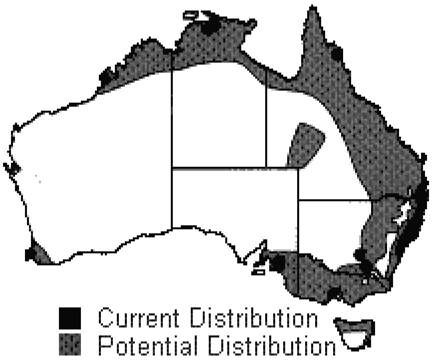

Figure 4. Current and potential distribution of Alligator Weed (Sainty and Associates 2001).

Alligator Weed has the ability to block waterways, deplete oxygen levels, out compete native aquatic plants, as well as prevent recreational use of waterways. Agriculturally it has the potential to reduce the productivity of turf, horticultural and pastoral production systems (Gunasekera and Bonila 2001).

Alligator Weed is a summer growing perennial herb, with mostly hairless stems which are hollow in the mature plant. The leaves are shiny, spear-shaped and have entire leaf margins. The leaves are about 2-7cm long and 1-2cm wide and the plant produces a white ball shaped flower (figure 5) (NWSEC 2000). In Australia, the plant reproduces asexually and is spread through plant fragments breaking off and floating downstream or being transported on machinery, in soil or turf. Alligator Weed grows extremely vigorously and is tolerant of many control methods.

Figure 5. Ball shaped flower and spear shaped leaves of Alligator Weed (Sainty and Associates 2001).

Once Alligator Weed becomes established, eradication and control is extremely difficult, as it is resistant to numerous chemicals and is able to survive in aquatic and terrestrial environments. Therefore, a high awareness of the weed and its potential impacts are required to enable early detection and ensure rapid control. Mechanical control is possible but fragments of the plant often break away causing infestations further downstream. Biological control is currently being evaluated but the current agent, Flea beetle (*Agasicles hygrophila*), only survives in warm, temperate areas (Ecos 1994).

Combinations of mechanical and chemical methods, coupled with regular monitoring and on-going management is required to bring the weed under control.

1.3.3 *Egeria densa* (Dense Waterweed, Leafy Elodea)

Egeria densa originated from Argentina, South-east Brazil and Uruguay and has been distributed around the world through its use as an ornamental plant in aquariums (ISSG 2005). Currently the weed is found in river systems on the east coast of Australia, ranging from north of Brisbane, Qld to Sydney, NSW (Figure 6). The plant prefers nutrient rich environments and slow moving water, but does not persist in rapidly moving waterways. *Egeria densa* obstructs water flow, out competes native vegetation, traps sediment (Figure 7) causes fluctuations in water quality and interferes with recreational activities. *Egeria densa* has the ability to cause substantial damage to waterways but is not declared a noxious weed in NSW.

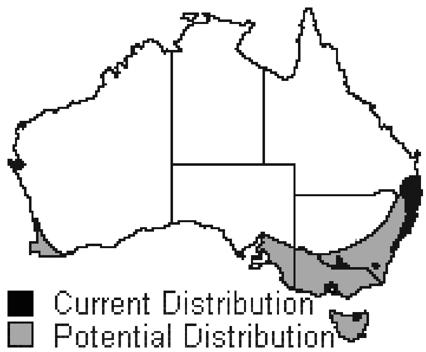

Figure 6. Current and potential distribution of *Egeria densa* in Australia (Sainty and Associates 2001).

Figure 7. *Egeria densa* traps sediment in the Hawkesbury-Nepean river, NSW (Sainty and Associates 2001).

Egeria densa belongs to the *Hydrocharitaceae* family and is a submerged perennial aquatic monocot. The stem of the plants are cylindrical, whilst the leaves occur in whorls (4-7 leaves) (Figure 8) at close intervals (2mm) along the stem. The leaves are 15-40mm long and 3-5mm wide, with minutely serrated margins. The plant produces distinctive 1.5 - 2cm wide white flowers with 3 petals flowering in spring and autumn (ISSG 2005). Separate plants produce male and female flowers, although only male flowers have been recorded in Australia. The plant spreads by fragmenting in autumn or through accidental transportation to new areas on boating and recreational equipment. The plant is cold tolerant and has been found to survive in the NSW Southern Tablelands, although it is primarily found along the coast.

Chemical control of this and other weeds is difficult in aquatic environments because of the risk of non-target impacts and water pollution. Mechanical removal of this weed is possible although the plant fragments easily when disturbed which can lead to new infestations. Currently there is no known biological control of the weed.

Figure 8. The leaves of *Egeria densa* occur in whorls (4-7 leaves) at close intervals (2mm) along the stem (Sainty and Associates 2001).

2 ENVIRONMENTAL RISK ASSESSMENT

2.1 Introduction

Consultation with stakeholders at the beginning of and during the project (Appendix 1) indicated there were a number of potential environmental risks associated with using the harvested aquatic weed for improving land condition in the Hawkesbury-Nepean Catchment. These include the potential for aquatic and terrestrial weeds to survive the composting process and spread on land or in water. In addition the aquatic weed compost (AWC) may contain high concentrations of nutrients and/ or heavy metals, which could impact on soil and water quality if applied at inappropriate rates. Similarly, the compost may contain phyto-toxic elements, such as herbicide residues, which may hinder vegetation establishment on land where the composts are to be applied.

However, the likelihood and consequence of these risks is unknown and so it is necessary to perform an environmental risk assessment to quantify these risks. As such, the objectives of this component of the project were to;

1) Determine whether the composting process employed destroys the viability of the harvested aquatic weeds.
2) Characterise the chemical, physical and biological characteristics of the composted product.
3) Apply the data generated to assess the environmental risk associated with the compost.
4) Develop strategies for managing any risks identified.

2.2 Materials and Methods

2.2.1 Composting process

Approximately 70,000 m^3 of aquatic weeds were harvested from the Hawkesbury-Nepean River in the several months prior to December 2004. A large amount of this material was stockpiled on the River bank near Cordner's Corner, Windsor (Figure 9). Approximately, 35,000 m^3 of the material was transported to the Hawkesbury City Council Waste Management Facility (HCCWMF) at South Windsor in April 2005 for processing. Processing and composting was undertaken by Bettergrow Pty Ltd, a commercial compost producer through a Memorandum of Understanding (MoU) negotiated with the Hawkesbury City Council and the NSW Department of Primary Industries.

The majority of the harvested aquatic weed consisted of Salvinia (*Salvinia molesta)* and *Egeria densa*, which rapidly decomposed to form a loose and lightweight organic material (Figure 9). Alligator weed (*Alternanthera philoxeroides*) was also present in the material (Figure 9). The harvested aquatic weed was blended with chipped municipal garden organics to increase the density of the material using a 1:1 ratio. After blending, the material was stockpiled in preparation for thermophilic composting in open windrows.

Figure 9. Stockpiles of Salvinia, *Egeria densa* and Alligator Weed harvested from the Hawkesbury River, near Windsor, NSW (December 2004).

There are four stages of composting, namely the i) mesophilic, ii) thermophilic, iii) cooling, iv) and maturation (Recycled Organics Unit 2002). The composting process is initiated during the mesophilic stage through the decomposition of organic material (Temperatures 20 - 45^{o}C), followed by the thermophilic phase when respiration and windrow temperature (> 45^{o}C) increase (Recycled Organics Unit 2002). The cooling and curing phase occurs once readily available organic carbon is depleted and is followed by the maturation phase, which is important to ensure the compost is stable and does not re-heat (Recycled Organics Unit 2002). In addition, temperatures > 55^{o}C are required during the thermophilic phase to ensure weeds, weed seeds and plant, animal and human pathogens are destroyed (Keen *et al*., 2002). However compost temperature varies throughout the windrow (Tee *et al.*, 1999) and so turning and mixing is necessary to ensure all of the material is exposed to these temperatures. As such, the Australian Standard for composted soil conditioners and mulches (AS4454) states "the minimum requirement for achieving pasteurisation is the appropriate turning of the outer material to the inside of the windrow so that the whole mass is subjected to a minimum of three turns with the internal temperature reaching a minimum of 55°C for three consecutive days before each turn (Standards Australia 2003)."

State and Local Government planning and environmental approvals were required to construct a compacted hard stand for establishing the compost windrows at the HCCWMF. This delayed the start of the composting process by several months. In addition, the short-term nature of the MoU meant that it was not commercially viable to purchase gravel, rocks and other material to construct the hard stand. Instead, the hard-stands were prepared by compacting the clay soil using heavy machinery.

Seven compost windrows (4m wide x 1.75 m high x 70 - 100m long) were formed in September 2005 on the hardstands at HCCWMF in an East-West orientation. These were turned four times at approximately 1-2 week intervals, using a commercial straddle turner (Figure 10). However, the straddle turner was not able to turn the material at the base (15-30 cm) of the windrow because of the risk of damaging the clay hard stand.

Figure 10. Straddle turner used to turn the compost windrows at the Hawkesbury City Council's Waste Management Facility.

The areas adjacent to the compost windrows were sprayed by contractors as necessary to control any weeds growing on the site.

The final quantity of compost produced from the initial 35,000 m^3 of harvested aquatic weed was 2000 m^3.

2.2.2 Monitoring and evaluation

Thermal destruction of harvested aquatic weeds

The bulk of the harvested material consisted primarily of Salvinia and low levels of *Egeria densa.* These weeds are killed by drying out and stockpiling on land, do not reproduce sexually and lack organs, such as tubers and rhizomes for storing carbohydrates (ISSG 2005). As such, the potential for them to survive the composting process is very low (B. Hennecke, UWS pers.comm 2005).

However, as Alligator Weed grows as both an aquatic (attached or free-floating) and terrestrial plant (Parsons and Cuthbertson 1992), there is potential for it to infest riparian and terrestrial land to which aquatic weed compost is applied. As such, it is necessary to ensure that any Alligator Weed in the harvested material does not survive the composting process. This was determined by adapting the experimental protocol developed by Bishop *et al.* (2002) and Keen *et al.* (2002) to examine the effects of temperature, period of exposure and turning regimens on the mortality of Alligator Weed in composted windrows.

Previously, Alligator Weed was growing on the stockpile of the harvested aquatic weed. However, the application of herbicide (glyphosate bioactive) and winter dormancy either killed or reduced the vigour of the Alligator Weed. As such, healthy Alligator Weed was collected from a site near Port Stephens, NSW, secured and transported to the experimental site at HCCWMF. A permit was obtained from the NSW DPI under the *Noxious Weeds Act* 1993 to collect and transport Alligator Weed for research purposes.

At the experimental site, viable Alligator Weed was placed in 225 nylon gauze bags (30 cm x 10cm); these were sealed using a heavy duty stapler and buried in the compost windrows according to their experimental treatment. The bags were clearly labelled using weatherproof tags and reinforced with brightly coloured webbing (Figure 11). This webbing enabled bag location to be quickly identified and also allowed bags to be easily retrieved from the compost windrow using a ratchet, winch and tripod.

Figure 11. Nylon gauze bags (30 x 10 cm) used to bury the alligator weed in the compost windrow.

<u>Effects of period of exposure and turning regimens on aquatic weed viability</u>

The experimental hypothesis was that subjecting the Alligator Weed to the composting process would provide 100% weed mortality. This was tested by comparing Alligator Weed mortality in bags which were subjected to different periods of exposure and turning regimens within the compost windrow. The experiment followed a factorial design consisting of 2 treatments (Control and Compost) x 4 periods of exposure (Phases) x 5 replicates (compost windrows).

The control treatment involved burying bags along the surface (0-15 cm) of the compost windrow. This ensured that any Alligator Weed mortality in the compost treatment could be attributed to the composting process and not natural mortality. One third (75) of the bags were subjected to the control treatment.

The compost treatment was designed to simulate the random mixing and movement of the bulk material which occurs within the windrow throughout the duration of the composting process. This was achieved by burying the bags of Alligator Weed at random at one of three vertical depths (0-15, 50-75 or 100-150 cm) along the apex of the windrow, using a hand held auger (Figure 12). Two thirds (150) of the bags were subjected to the compost treatment.

Figure 12. Illustration of the technique used to bury bags containing alligator weed in compost windrows at the experimental site.

The bags were recovered from the windrow at the end of the first composting phase (Phase 1). After the windrow was turned and re-formed, most of the bags being subjected to the compost treatment were returned to one of the three depths at random, whilst most of the control bags were returned to the surface of the windrow.

Table 1. The number of gauze bags containing Alligator Weed, which were subjected to control (0-15cm) and compost (0-15, 50-75, 100-150cm) treatments in windrows containing harvested aquatic weeds and municipal garden organics, during each composting phase.

Treatment	Burial Depth (cm)	Block 1	2	3	4	5	Total buried
			Phase 1				
Control	0-15	15	15	15	15	15	
Compost	0-15, 50-75, 100-150	30	30	30	30	30	
	Total	45	45	45	45	45	225
			Phase 2				
Control	0-15	12	12	12	12	12	
Compost	0-15, 50-75, 100-150	24	24	24	24	24	
	Total	36	36	36	36	36	180
			Phase 3				
Control	0-15	9	9	9	9	9	
Compost	0-15, 50-75, 100-150	18	18	18	18	18	
	Total	27	27	27	27	27	135
			Phase 4				
Control	0-15	6	6	6	6	6	
Compost	0-15, 50-75, 100-150	12	12	12	12	12	
	Total	18	18	18	18	18	90

This process was repeated at the conclusion of Phases 2, 3 and 4. At the conclusion of Phases 1, 2 and 3, 45 bags (15 control and 30 compost) were permanently removed from the windrow. At the end of Phase 4, the remaining 90 bags (30 control and 60 compost) were removed (Table 1). The dates of burial, collection and windrow turning are summarised in Table 2. The period between retrieval and re-burial was generally 24-48 hours and during this time the bags were watered and covered to prevent any potentially viable Alligator Weed fragments within them from dehydrating.

Table 2. Dates when gauze bags containing Alligator Weed were buried in and retrieved from compost windrows in relation to the date of windrow turning.

Phase	Bags buried	Bags retrieved	Windrow turned
1	23-Sep-05	28-Sep-05	30-Sep-05
	26-Sep-05*	28-Sep-05	30-Sep-05
2	1-Oct-05	5-Oct-05	7-Oct-05
3	8-Oct-05	18-Oct-05	21-Oct-05
4	21-Oct-05	27-Oct-05	28-Oct-05

*Time and weather constraints meant that Blocks 4 and 5 were buried at a later date than Blocks 1-3 in Phase 1.

The contents of the removed bags were placed in pots containing sterilised river sand, which were watered, randomised and placed in a glasshouse at the Elizabeth Macarthur Agricultural Institute (Figure 13), which is 70km from the experimental site. This was performed as soon as possible after removal (<24 hours). The glasshouse was maintained at 30^{o}C and 60% humidity, which provided near optimal conditions for Alligator Weed growth and development (B. Hennecke, UWS pers.comm 2005). Each pot was watered for one minute every two hours using an automated watering system. Each pot was assessed for signs of viable Alligator Weed over an eight week period; survival was determined as any sign of regrowth or new shoots on the potted material during this time. Once monitoring was completed, any remaining plant material was collected and incinerated. The sand was heat treated at 70^{o}C for five consecutive days and all of the pots used in the trial were steamed to ensure no plant fragments survived.

Figure 13. Alligator Weed growing under controlled glasshouse conditions (30^{o}C and 60% relative humidity) two weeks after retrieval from compost windrows and being subjected to different composting treatments.

Effects of temperature on alligator weed mortality

Temperature profiles in the compost windrows were measured to examine the effect of temperature on Alligator Weed mortality. This was achieved using two approaches.

The first approach involved inserting a stainless steel temperature probe to depths of 0-15, 50-75 and 100-150cm to record the temperature of the bulk windrow (Figure 14). This was performed 1-2 times/week during each composting phase. Readings were taken at 3 random locations within each of the five windrows or experimental blocks.

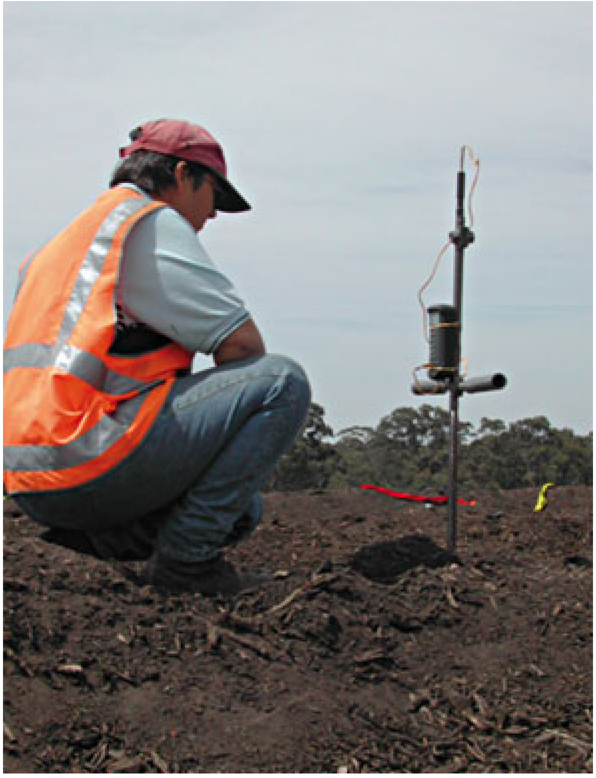

Figure 14. Illustration of the temperature probe used to monitor the temperature of the windrow at 0-15, 50-75 and 100-150cm depths.

In addition, Dallas iButton TMEX (MAXIM Integrated Products Inc., USA) high capacity, general purpose temperature data loggers were placed in three bags corresponding to burial depths of 0-15, 50-75 and 100-150cm, within each block, to continuously monitor temperature at different locations within the windrow. The bags containing the temperature data loggers corresponded to those which were subjected to the control and compost treatments for all four composting phases to ensure temperature was recorded for the duration of the experiment. In addition, 5 temperature data loggers were inserted into nylon stockings, which were attached to stakes located at random on top of the 5 compost windrows to record ambient air temperature across the experimental site.

The temperature data loggers recorded the temperature at 30 minute intervals. At the end of each composting phase the bags were retrieved, the temperature data loggers were recovered and the data was downloaded onto a notebook computer. After the data was downloaded, the temperature data loggers were re-programmed and returned to the bag, for subsequent re-burial. The time of burial and retrieval was recorded and correlated with the downloaded data so that the data which was recorded outside the periods of burial could be excluded.

Site monitoring

During the experimental phase, weekly site surveys were conducted to identify any Alligator Weed, which was growing on the compost windrows and/ or adjacent areas. After the experimental component was completed the surveys were only conducted on a semi-regular basis (i.e. every 1-3 months).

2.2.3 Compost characterisation

At the conclusion of composting, 5 composite samples (10-12 kg) were obtained by shovelling 1-2 kg of aquatic weed compost from 10 random positions within each windrow into plastic garbage bins. The composite aquatic weed compost samples were analysed for a range of physical, chemical and biological characteristics following the procedures outlined by (Standards Australia 2003). Particular parameters of interest included nutrients, heavy metals and pesticide residues. The results for each parameter were compared against the limits defined in (Standards Australia 2003), the draft compost specifications developed by the DECC and HNCMA, and data on the characteristics of other compost prepared from source separated garden organics (Dorahy *et al.*, 2005).

2.2.4 Statistical analysis

Effects of composting on Alligator Weed mortality

The effect of composting on Alligator Weed mortality was analysed using a General Linear Model (GLM), with errors assumed to be binomially distributed. Deviance values were calculated and Chi probability used to determine whether treatment effects were statistically significant at the $P<0.05$ level.

Mean temperature at each monitoring position (0-15cm, 50-75cm, 125-150cm and ambient) was calculated for both the temperature data loggers and temperature probes. This was plotted against cumulative days of composting and date, respectively, to examine changes in windrow temperature at different depths over time.

The mean daily temperature (Day degrees, DD) within each bag containing a temperature data logger (Control and Variable), was also determined. DD were used to calculate the cumulative day degrees Celsius (CDD (^{o}C)) each bag was exposed to over the 4 phases of composting. A logit function was then used to determine whether Alligator Weed mortality (p) was correlated with CDD (log scale) using linear regression.

Compost characterisation

The variability associated with the compost was determined by calculating the mean, standard error and range (minimum and maximum) for each chemical, physical and biological parameter of interest.

2.2.5 Risk Analysis

Preliminary analysis identified four key potential environmental risks associated with using the harvested aquatic weed for improving land condition in the Hawkesbury-Nepean Catchment:

a) Survival and spread of weeds (terrestrial and aquatic)

b) Eutrophication of waterways arising from applying composts with high nutrient status

c) Accumulation of heavy metals in the environment from applying composts with high heavy metal concentrations

d) Phytotoxicity from applying immature composts or composts containing herbicide residues

A qualitative risk analysis was performed using the matrix defined by Standards Australia to quantify the level of risk associated with each of these key parameters of concern (Table 3). This involved assigning a score to the likelihood of each key risk occurring and its consequence, based on the information generated from monitoring the compost windrows and characterising the final compost product. The scores from Likelihood (1-5) and Consequence (1-5) were multiplied to derive a value associated with the overall risk. This value was then compared with the range defined by Standards Australia (2000) to determine whether the risk was high, medium or low (Table 3).

Table 3. Qualitative matrix used to assess the likelihood and consequence of environmental risk associated with compost prepared from harvested aquatic weed (Adapted from Standards Australia 2000).

Likelihood	---------------------------------- Consequence ------------------------------				
	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
Almost certain (5)	5	10	15	20	25
Likely (4)	4	8	12	16	20
Possible (3)	3	6	9	12	15
Unlikely (2)	2	4	6	8	10
Rare (1)	1	2	3	4	5

Legend: 15-25 – High; 5-12 – Moderate; and 1-4 – Low

2.3 Results

2.3.1 Monitoring and evaluation

The effect of composting on Alligator Weed mortality was highly significant ($P<0.001$) at each composting phase (Table 4). By the end of Phase 4, less than 2% of the bags subjected to composting had any signs of viable Alligator Weed (Table 4).

Table 4. Effect of thermophilic windrow composting on the mortality of alligator weed over four phases of composting in compared to untreated controls.

Phase	--------- Mortality -------- (Proportion)		Deviance	Chi. Probability
	Control	Compost		
1	0.067	0.333	4.5	<0.001
2	0	0.8	32.2	<0.001
3	0	0.967	49.8	<0.001
4	0	0.983	105.7	<0.001

The data from the temperature data loggers indicated that temperature in the bags buried at the surface of the compost windrow (0-15cm) fluctuated in accordance with ambient air temperature (Figure 15). However, temperatures in the bags buried at 50-75cm and 125-150cm were fairly constant and generally ranged between 50-55^{o}C and 40-45^{o}C, respectively (Figure 15).

The data obtained via instantaneous readings using the temperature probe was similar to that obtained using the temperature data loggers, although it was more variable (Figure 16).

A highly significant (*P*<0.001) relationship was observed between Alligator Weed mortality (logit p) and cumulative day degrees (log CDD) (Table 5). Back transformation of the original and modelled data revealed a strong curvi-linear relationship between Alligator Weed mortality and cumulative exposure to composting (Figure 17).

Table 5. Coefficients derived from the linear regression of Alligator Weed mortality (logit p) and cumulative day degrees (logCDD).

Coefficient	Estimate	s.e.	Prob.
Intercept	-11.38	2.23	
logCDD	4.854	0.87	<0.001

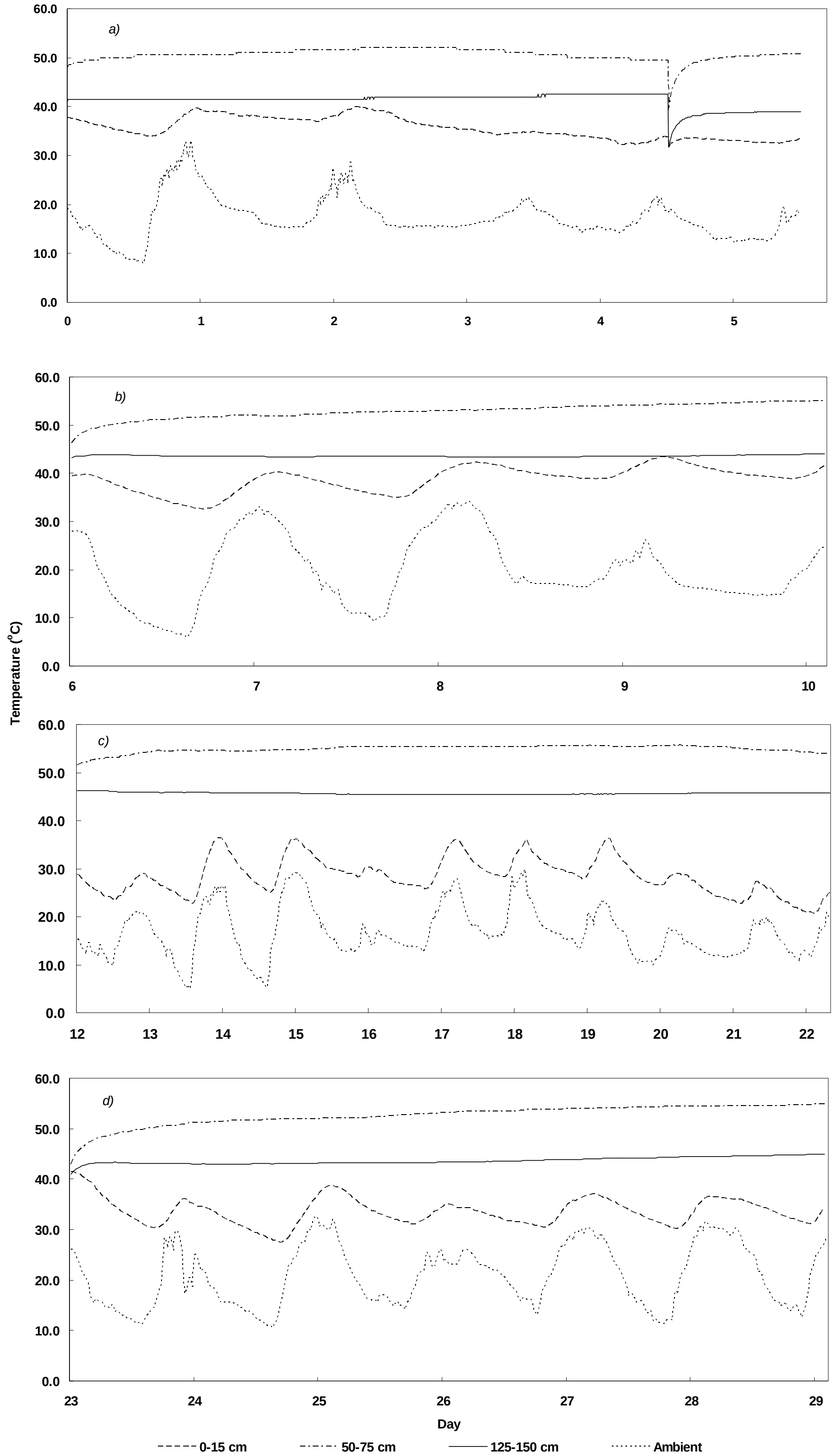

Figure 15. Comparison of ambient temperature and temperatures at different depths (0-15, 50-75 and 125-150cm) within compost windrows containing harvested aquatic weed during Phases 1-4 (a-d) of composting.

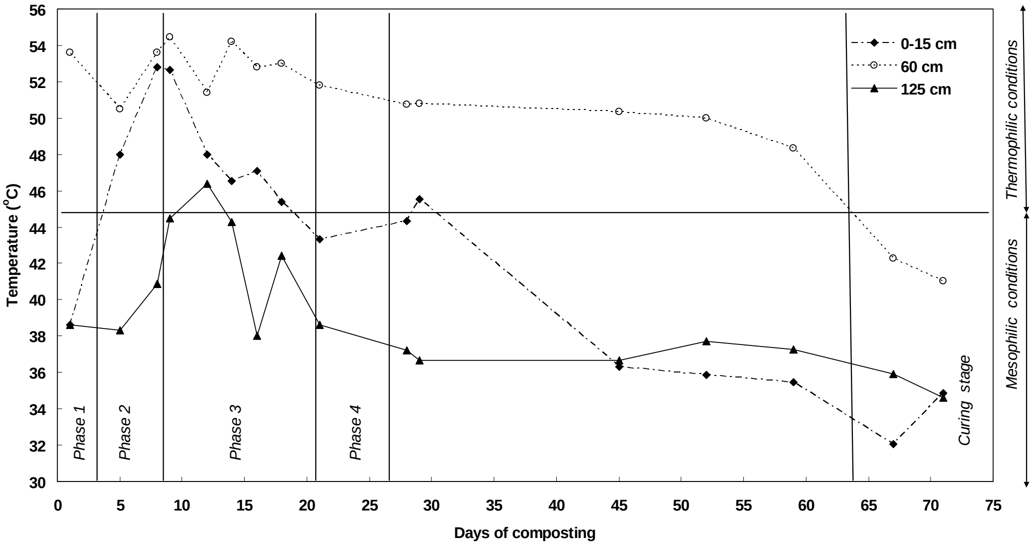

Figure 16. Instantaneous temperature readings taken at different depths (0-15, 60 and 125cm) within windrows during different phases of composting between 1/9/2005 and 6/12/2005).

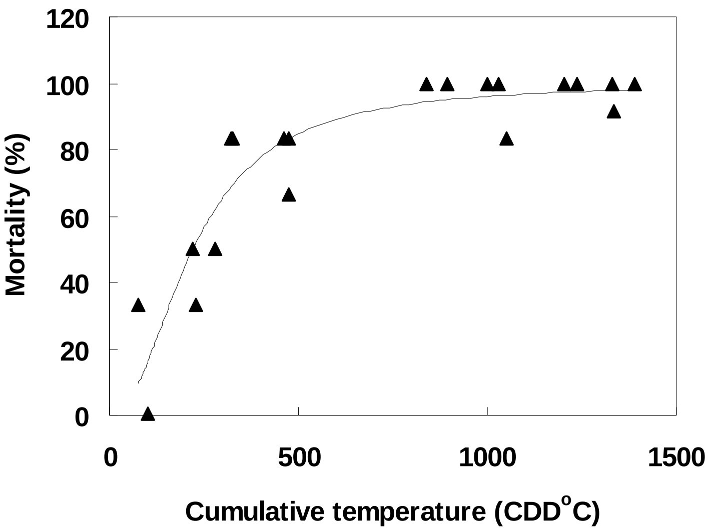

Figure 17. Back transformed relationship between cumulative temperature and mortality of Alligator Weed subjected to composting as described by the linear regression model: logit p = -11.38 + 4.854 log(CDD) (*P*<0.001).

<u>Site monitoring</u>

A number of Alligator Weed plants were observed growing around the experimental site at the base of the composting windrows (Figure 18). In addition it was also found on the banks of earthen bunds around the windrows and in static piles of uncomposted material (Figure 19). Prophylactic spraying was effective in controlling the Alligator Weed observed between November and December 2005, although some weeds were still present at the site in May 2006 (Figure 18).

Figure 18. Alligator Weed growing at the base of a compost windrow containing harvested aquatic weed.

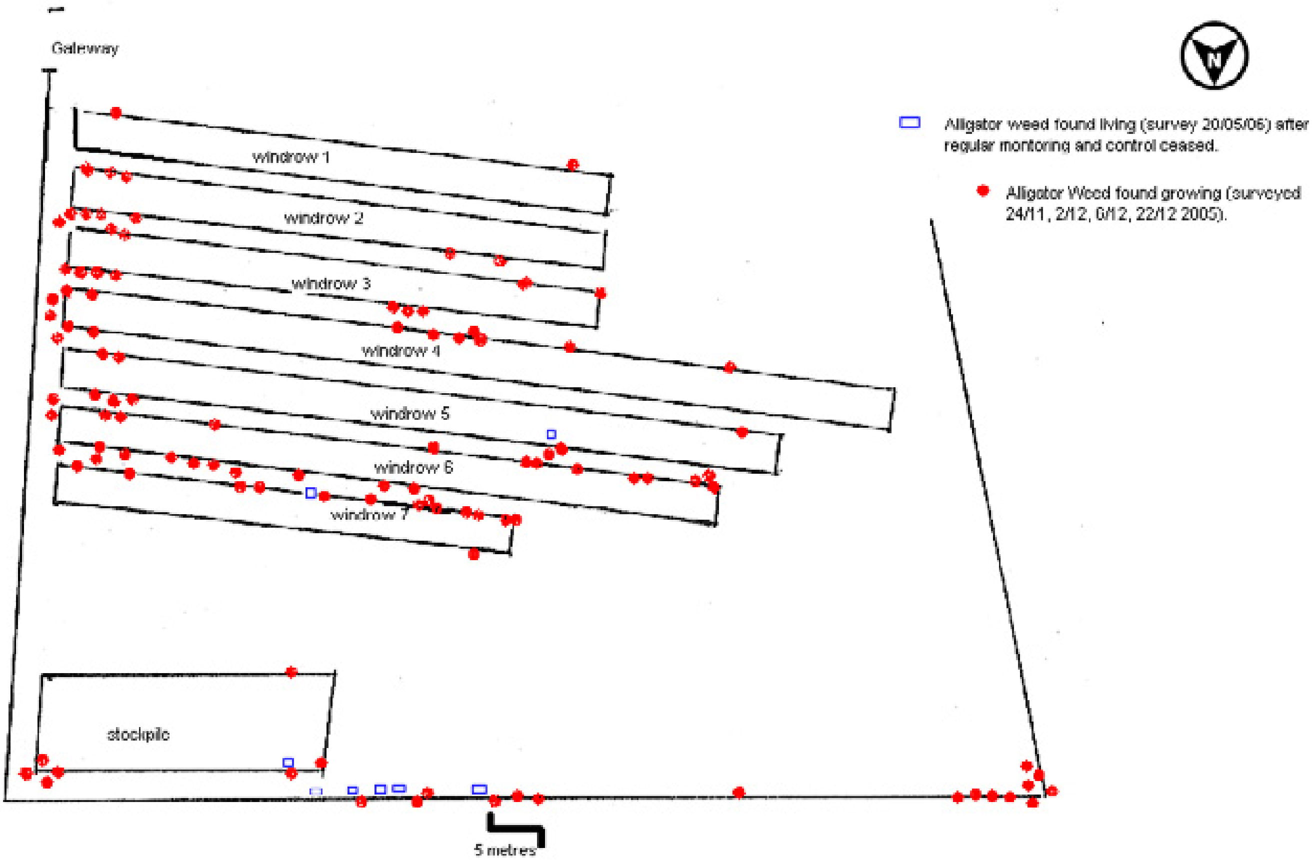

Figure 19. Schematic representation of the distribution of Alligator Weed around the site where harvested aquatic weed was composted between November 2005 and May 2006.

2.3.2 Compost characterisation

The low standard error (s.e.) values of the chemical, physical and biological parameters measured indicated that compost quality was fairly consistent (Tables 6-8). Further, it was within most of the limits prescribed by Standards Australia (2003) for composted soil conditioners and mulches.

The aquatic weed compost (AWC) was slightly alkaline (pH 7.2) and had moderate Electrical Conductivity (EC 2.2 ± 0.2 dS/m), which is comparable to the values reported by Dorahy *et al*. (2005) for similar types of composts prepared from source separated garden organics (Table 6). The AWC had lower concentrations of total nitrogen, phosphorus and calcium than equivalent products (Table 6), whilst the proportion of nitrate to ammonium was high (~38:1) (Table 6). The AWC contained 19.6 ± 1.1% organic matter, which is less than the limit of ≥ 25% prescribed by Standards Australia (2003).

The AWC contained 95 ± 1% particles <15mm retained indicating it would be classified as a composted soil conditioner by Standards Australia (2003). The toxicity index (97 ± 8 mm) for AWC was greater than the limit of 60mm (Table 7). The mean percentage of stones, and lumps of clay (6.8 ± 0.7%) was above the AS4454 maximum limit of 5%. The AWC met the Australian Standard for Glass, metal and rigid plastics > 2mm and light plastics >5mm (≤ 0.5% and ≤ 0.05%, respectively). However, it did not meet the more restrictive limits for these parameters (≤ 0.05% and ≤0.005%, respectively) proposed by the DECC for “rehab soil conditioners”.

The heavy metal and organic contaminant concentrations in the aquatic weed compost were all within the Grade A limits defined by NSW EPA (1997) (Table 8), making it suitable for unrestricted use. However, mean Zn concentration (198 mg/kg) was only just below the 200 mg/kg limit for this heavy metal (Table 8).

Table 6. Chemical characteristics of aquatic weed compost (AWC) in comparison with those of composted garden organic mulches, soil conditioners (SC) and blended soil conditioners (BSC) derived from source separated garden organics in the Sydney basin (Adapted from Dorahy *et al.*, 2005), as well as the numerical criteria defined in Standards Australia (SA) (2003).

	AWC (n=5)	Mulch (n=8)	SC (n=11)	BSC (n=10)	AS4454 (Standards Australia 2003)
	----------	---------- (mean ± s.e.)	----------	----------	
pH	7.2 ± 0.0	6.5 ± 0.3	6.9 ± 0.2	7.2 ± 0.2	5.0 - 7.5[A]
EC (dS/m)	2.2 ± 0.2	1.2 ± 0.2	2.2 ± 0.2	3.0 ± 0.5	No limit
Soluble P (mg/L)	0.4 ± 0.1	2.7 ± 0.5	2.5 ± 0.7	10.5 ± 4.3	≤5[B]
NH_4^+-N (mg/L)	0.7 ± 0.2	13.2 ± 7.7	10.7± 5.3	87.8 ± 27.9	<200
NO_3^--N (mg/L)	26.4 ± 2.9	0.9 ± 0.3	2.4 ± 1.6	88.9 ± 51.7	≥10[C]
NH_4^+ + NO_3^--N (mg/L)	26.6 ± 2.9	15.9 ± 7.5	14.7 ± 4.8	177.1 ± 52.6	>200[C]
[§]OM (%)	19.6 ± 1.1	59.2 ± 2.1	31.1 ± 2.1	25.9 ± 1.9	≥25
N (%)	0.6 ± 0.1	0.7 ± 0.1	1.0 ± 0.1	1.3 ± 0.2	≥0.6[C]
P (%)	0.1 ± 0.0	0.1 ± 0.0	0.2 ± 0.0	0.4 ± 0.1	≤0.1[B]
Ca (%)	0.6 ± 0.1	0.7 ± 0.1	1.7 ± 0.3	2.1 ± 0.4	-
Mg (%)	0.2 ± 0.0	0.1 ± 0.0	0.2 ± 0.0	0.3 ± 0.0	-
Na (%)	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.2 ± 0.0	<1[E]
B (mg/kg)	18.3 ± 9.0	12 ± 1	11.4 ± 1.2	10 ± 1	<200[F]

[A] If pH>7.5 determine total $CaCO_3$ content; [B] for products which claim to be for P sensitive plants; [C] if a contribution to plant nutrition is claimed. No requirement for composted mulches; [D] for all products except those labelled as manure or mushroom substrate, for which the EC criteria are more appropriate. No requirement for composted mulch products; [E] or at least 7.5 moles Ca plus Mg for each mole of Na in the dry matter. [F] Products with total B <100 can have unrestricted use. [G] for retail sale, all products shall meet the Class A classification of the 'Environmental Guidelines: Use and disposal of biosolids products' (NSW EPA 1997), for unrestricted use; [§]Dry matter basis.

Table 7. Physical and biological characteristics of compost prepared from harvested aquatic weed in comparison with the limits defined in Standards Australia (2003).

Parameter	Mean ± s.e.	AS4454
Physical characteristics		
Moisture content (%)	25 ± 2	> 25
Wettability (min)	6.6 ± 1.4	< 7
Particle size grading (<15mm retained) (%)	95 ± 1	> 20 – Soil conditioner
Particle size grading (>15mm retained) (%)	5 ± 1	20 > x >70 – Fine mulch
Glass, metal, rigid plastics (>2mm) (%)	0.2 ± 0.1	≤ 0.5
Light plastic > 5mm (%)	0.04 ± 0.02	≤ 0.05
Stones and lumps of clay > 5mm (%)	6.8 ± 0.7	< 5
Biological characteristics		
Toxicity Index (mm)	97 ± 8	≥ 60

Table 8. Heavy metal and organic contaminant concentrations in compost prepared from harvested aquatic weed in comparison with the limits defined by NSW EPA (1997).

Parameter	Mean ± s.e.	Grade A limit
Heavy metals (mg/kg)		
Arsenic (As)	9.1 ± 0.6	< 20
Cadmium (Cd)	<1.0	< 3
Chromium (Cr)	18 ± 1.7	< 100
Copper (Cu)	27 ± 1.7	< 100
Lead (Pb)	63 ± 4.3	< 150
Mercury (Hg)	<0.1	< 1
Nickel (Ni)	9 ± 0.5	< 60
Selenium (Se)	<3.0	< 5
Zinc (Zn)	198 ± 30	< 200
Organics (mg/kg)		
DDT/DDD/DDE	<0.02	< 0.5
Aldrin	<0.02	< 0.02
Dieldrin	<0.02	< 0.02
Chlordane	<0.02	< 0.02
Heptachlor	<0.02	< 0.02
HCB	<0.02	< 0.02
Lindane	<0.02	< 0.02
BHC	<0.02	< 0.02
PCB's	<0.1	< 0.2

2.4 Discussion

2.4.1 Risk Analysis

Survival and spread of terrestrial and aquatic weeds

The Australian Standard for composted soil conditioners and mulches (AS4454) recommends that material within compost windrows should be subjected to temperatures in excess of 55°C for three consecutive days (Standards Australia 2003). Our monitoring revealed that the temperature in the middle of the compost windrows (50 - 75 cm depth) was above the range required for thermophilic composting (> 45°C, ROU 2001), but rarely exceeded temperatures required for pasteurisation (>55°C) (Figure 15). This is probably due to the harvested material being stockpiled for 6 months prior to composting and not having fresh garden organics feedstock added to it before composting commenced (2.2.1). Fresh garden organics would have provided a source of available nitrogen and phosphate for the degrading microbes present and accelerated the rate of composting (Whitney 1996).

Despite this, our results demonstrate a >98% (1.8 log) reduction in Alligator Weed survival was achieved by subjecting it to composting (Table 4) and that mortality was a function of temperature and period of exposure (Figure 17). As such, nearly 100% control could be achieved by ensuring all of the material is exposed to at least 1000 CDD (Figure 17). It should be noted the percentage survival (1.7%) was due to only a single plant surviving 4 phases of composting (Table 4). This plant died in subsequent monitoring.

We accept that there is a lower temperature threshold, below which the relationship presented in Figure 17 would not hold and Alligator Weed could survive indefinitely. This fact is reflected in the low mortality rates (~ 0%) of the Alligator Weed subjected to the control treatment (Table 4). Larney and Blackshore (2003) reported that lethal weed temperatures varied among weed species, ranging from 38.9 to 66.3°C. These workers used a base temperature of 40°C in their study of weed seed viability in composted beef cattle feedlot manure. Murphy (2003) concluded that that Alligator Weed would be killed when exposed to temperatures between 40 and 50°C for 72 hours. This, combined with the results, suggest that temperature and exposure regime recommended by Standards Australia (2003) (>55°C for three consecutive days) should minimise the risk of Alligator Weed surviving the composting process.

Factors other than temperature which may have contributed to Alligator Weed mortality during composting include phytotoxic leachates from the compost or soil-compost mixture (Ligneau and Watt 1995; Marchiol *et al*. 1999; Ozores-Hampton *et al*. 1999), ammonia toxicity to viable weed seeds (Larney and Blackshaw 2003) and windrow temperature/moisture interactions (Eghball and Lesoing 2000).

Of concern is the growth of Alligator Weed which was recorded during site monitoring (Figures 10 and 11). These plants were observed growing at the base of the compost windrow, as a result of it not being completely turned for fear of damaging the clay hard stand on which the windrows were established (Section 2.2.1). The temperatures in this zone of the windrow (125-150 cm) generally ranged from 40 to 45°C (Figure 15) indicating that thermophilic conditions (> 45°C) were not always achieved and that plants could survive if they were not subjected to higher temperatures.

Using Alligator Weed as an indicator organism, it is likely (Score = 4) that harvested aquatic weed, which was not subjected to thermophilic conditions, could contain viable fragments of terrestrial and aquatic weeds. This would have major consequences (Score = 4) with respect to water quality and ecology if this material was applied to areas of the Hawkesbury-Nepean Catchment where Alligator Weed does not occur. Therefore, the overall environmental risk of aquatic and terrestrial weeds surviving the composting process and spreading is high (Table 9) and requires on-going management.

Eutrophication of waterways

The second component of this project examined the ability of compost prepared from harvested aquatic weed to control runoff and sediment and nutrient transport from degraded catchments. This issue will be explored further in Chapter 3 of this report. However, the localised areas of application, suggest the likelihood and consequence of environmental risks associated with this factor is low (Table 9).

Accumulation of heavy metals

The mean concentration of heavy metals in this batch of compost prepared from harvested aquatic weed were lower than the Grade A limits defined by NSW EPA (1997) and adopted by Standards Australia (2003). However, some of the samples had zinc (Zn) concentrations greater than the limit of 200 mg/kg for unrestricted use (NSW EPA 1997). Application rates would therefore need to be limited in some instances so that the maximum allowable contaminant concentration for Zn (200 mg/kg) is not exceeded.

Mann (2004) analysed fresh samples of Salvinia harvested from South Creek and the Hawkesbury-Nepean River and reported heavy metal concentrations which were much lower than the limits prescribed by Standards Australia 2003. Salvinia comprised the bulk of the material which was composted and analysed in our study and explains why the heavy metal concentrations reported in Table 8 were so low. Consequently, the likelihood of heavy metals in the aquatic weed compost accumulating in the environment and causing environmental impacts is low (Table 9).

However, aquatic weeds have been used successfully to remove heavy metal contaminants from waterways and Alligator Weed has been shown to bioaccumulate pollutants such as lead, chromium, cadmium and copper (Naqvi *et al.*, 1993; Naqvi and Rizvi, 2000). This highlights the need to consider the source of feedstock when assessing the risk of the final composted product containing heavy metals. Similarly, it illustrates the importance of testing each batch of compost for heavy metal contamination.

Phytotoxicity

The temperature probe measurements (Figure 16) indicated that the composted windrows went through the four stages of composting (2.2.1), finishing with curing and maturation. This was reflected in the chemical and biological characteristics of the final product which had a high proportion of nitrate to ammonium (~38:1) (Table 6) and a toxicity index > 60 mm (Table 7). Further, the concentrations of pesticide residues as indicated by organic contaminants (Table 8) were less than the Grade A limits defined by NSW EPA (1997) and adopted by Standards Australia (2000) for unrestricted end uses. Moreover, glyphosate bioactive, which is a non-residual chemical (Monsanto 2004) was the only pesticide used to control weeds on the site. As such, the likelihood and environmental risk of the compost prepared from harvested aquatic weed causing phytotoxicity would be low (Table 9).

Table 9. Summary of matrix used to determine the level of environmental risk associated with compost prepared from harvested aquatic weed.

	Likelihood (1-5)	Consequence (1-5)	--------- Risk --------- Score	Category
Survival and spread of weeds	4	4	16	High
Eutrophication of waterways	1	4	4	Low
Accumulation of heavy metals	1	3	3	Low
Phytotoxicity	1	3	3	Low

2.4.2 Risk management

The site monitoring conducted at the Hawkesbury City Council Waste Management Facility indicates the composting process needs to be improved to reduce the likelihood of viable aquatic and terrestrial weeds occurring in the final product.

Monitoring and evaluation revealed some alligator weed growing at the base of the windrow (Figure 18) and around the site (Figure 19). Better turning and mixing of the compost windrow is required to ensure all of the input material, especially at the base of windrow, is exposed to the composting process. This could be achieved by improving the standard of the clay hardstand to enable the straddle turner to invert and mix the entire windrow.

Secondly, addition of fresh feed stock (eg. source separated garden organics), at the beginning of the composting process, would help increase the temperatures (>55^{o}C) within the windrows so that a higher rate of decomposition and pasteurisation could be achieved (Whitney 1996). Thirdly, increasing the number of composting phases from 4 to 5 would increase the period in which the feedstock was exposed to composting and reduce the percentage of viable plant material surviving the composting process (Churchill *et al.*, 1995). Moreover, increasing the size of the windrows would reduce the surface area to volume ratio and increase the temperature inside the windrow (Michel 1996).

It is essential to regularly monitor temperature profiles throughout the windrow to ensure the required temperatures (>55^{0}C) are being achieved. Likewise, on-going site monitoring and recording of weed growth combined with prophylactic spraying to control weed growth is also necessary. Integrating these approaches should minimise the risk of composts prepared from harvested aquatic weeds would not containing viable weeds and increase stakeholder confidence in the quality of the final product.

The current batch of aquatic weed compost should have restrictions on its end use because it carries a higher than acceptable risk of Alligator Weed surviving the composting process and spreading in both aquatic and terrestrial environments. Firstly, only the material from the top 50% of the windrow should be used. Application should be limited to land within catchments where Alligator Weed is already present or where the risk of alligator weed infesting riparian areas is low. The land application site would require monitoring for the occurrence of Alligator Weed and be sprayed as necessary. The remaining 50% of the windrows should be subjected to additional processing following the recommendations outlined above.

Good site hygiene is also important for minimising the spread of weeds onto and off site. Practices need to be implemented to reduce the risk factor such as: keeping the unprocessed, immature and mature batches of compost isolated from each other; turning them in the order of most mature to least mature to avoid re-introducing viable weeds or contaminants; ensuring all staff are aware of the risks associated with aquatic weeds and adequately trained to identify and control any weeds identified; ensuring any loads leaving the site are always covered; and ensuring all equipment and machinery involved in the handling and transportation of the compost is cleaned prior to handling and is clean upon leaving the site. The development of a site management protocol could assist in implementing these recommendations.

There do not appear to be any appreciable environmental risks from nutrients, heavy metals, organic compounds and phytotoxicity in the compost evaluated in this study. However, it would be advisable to test future batches against the criteria defined by Standards Australia (2002), given compost quality is influenced by the characteristics and source of feedstock, method of processing and as such can vary from site to site.

2.5 Conclusions and recommendations

This research, using Alligator Weed as an indicator organism, has shown that composting is an effective method of reducing the viability of aquatic weeds. Weed mortality was shown to be a function of temperature and period of exposure, whereby nearly 100% control could be achieved by ensuring all of the material is exposed to at least 1000 cumulative day degrees Celsius (CDD ^{o}C). However, the lack of an appropriate hard stand at the site meant that some of the material at the base of the windrow was not exposed to these conditions. Consequently, viable Alligator Weed was observed growing at the base of the windrows and elsewhere on the site.

The final composted product was slightly alkaline (pH 7.2), but relatively low in plant nutrients and organic matter when compared to equivalent composted products derived from source separated garden organics. The mean heavy metal and organic contaminant concentrations in the aquatic weed compost were all less than the Grade A limits defined by NSW EPA (1997).

The main environmental risk associated with the compost relates to the survival and spread of Alligator Weed, which is both an aquatic and terrestrial weed. As such it is recommended land application of the compost derived from the present investigation be restricted to catchments where Alligator Weed is already present.

The risk associated with weed survival in future composting operations could be reduced by optimising the composting process though:

- constructing a hard stand which will enable adequate turning and mixing all of the material;
- adding feedstock, such as source separated garden organics, to increase the temperatures within the windrow to enable more complete thermophilic decomposition (>45^{o}C) and pasteurisation (>55^{o}C);
- extending the period of exposure, by increasing the number of compost phases from 4 to 5;
- Using temperature probes and data logging devices (temperature data loggers) to ensure required temperatures are achieved; and
- Monitoring the windrows and adjacent areas for the presence of Alligator Weed and other weeds and conducting prophylactic spraying when necessary.

Compost quality can vary from site to site and so future batches should be tested against the criteria defined by Standards Australia (2003) to assess the risk of environmental impacts from phytotoxicity, eutrophication and heavy metals.

3 EROSION CONTROL PERFORMANCE

3.1 Introduction

3.1.1 Erosion control performance of compost prepared from harvested aquatic weed

Previous work by Wong *et al.* (2005) has demonstrated the potential for composted soil conditioners and mulches to control erosion from degraded land in catchments via reducing sediment transport and promoting revegetation. Restoring land condition in the upper parts of catchments is important for downstream water quality. Poor water quality in the Hawkesbury-Nepean River arising from elevated nutrient concentrations, reduced environmental flows and high temperatures have lead to the outbreak of the aquatic weeds which are the focus of this study. As such, beneficially reusing the compost prepared from harvested aquatic weed to improve land condition in the Hawkesbury-Nepean Catchment, would help ‘close the loop’ by addressing some of the issues which have lead to aquatic weed outbreaks downstream.

However to the authors’ knowledge, currently little to no information exists regarding the erosion control performance of compost prepared from harvested aquatic weed. Therefore it is necessary to quantify the potential for it to reduce runoff and the transport of sediments and nutrients associated with it.

3.1.2 Evaluating rates and methods of applying recycled organics to degraded catchments

Through its Catchment Protection Scheme, the Hawkesbury-Nepean Catchment Management Authority has identified a number of degraded areas which are saline and/or sodic and pose a significant risk to water quality. Conventionally, earthworks are undertaken to reform these degraded areas. The slopes are then deep ripped along the contour in preparation for tube stock planting and harrowed prior to seeding with a pasture mix. Meadow hay may then be applied at a depth of approximately 20-50 mm (200 - 500 m^3/ha) to stabilise the site prior to vegetation establishment.

As part of the current DECC/ HNCMA/ DPI Joint partnership project, the Hawkesbury-Nepean Catchment Management Authority has established a number of large scale demonstration trials, using composted soil conditioners and mulches, to rehabilitate a number of these degraded sites (Figure 20).

Figure 20. Example of large scale demonstration sites established near Goulburn by the Hawkesbury Nepean Catchment Management Authority, which are evaluating the use of composted soil conditioners and mulches in catchment rehabilitation works.

The soil conditioners are surface applied and then incorporated into the soil using harrows, whilst the mulches are applied to the soil surface after harrowing. This involves two spreading and handling operations, which adds to the cost of using composts. As such, the HNCMA has trialled ripping the soil, harrowing it and applying a blend containing 40% soil conditioner and 60% mulch to a depth of 50mm on the soil surface in one operation (Figure 21).

Figure 21. Example of application of a 40/60 blend of composted soil conditioner and mulch to the surface of a degraded catchment near Goulburn. Note the rip lines and mounds for tube stock planting.

Both application methods have promoted site stabilisation and revegetation. The trials have demonstrated that composted mulches and soil conditioners are effective in stabilising and revegetating degraded sites. However, uncertainty surrounds which application method optimises product performance and whether application rates can be reduced to minimise costs associated with using composted mulches and soil conditioners.

3.1.3 Objectives

The objectives of this component of the project are to:

1) Evaluate the ability of compost prepared from harvested aquatic weed to reduce runoff and sediment transport from runoff plots.
2) Examine the effect of application method on erosion control performance.
3) Investigate the effect of reduced application rates on erosion control performance.
4) Use the outcomes of this work to assist in developing new markets for composted mulches and soil conditioners.

3.2 Materials and Methods

3.2.1 Site Description

The trial site was located on a hillside (slope 10%) in the Night Paddock at the NSW DPI's Centre for Recycled Organics in Agriculture (CROA). It was characterised by a permanent pasture, dominated by kikuyu (*Pennisetum clandestinum*) and located on a Red Chromosol (Isbell 1996). The Department of Lands were engaged to remove the vegetation and soil (0-30 cm) (Figures 22 and 23) to simulate a degraded site which is denuded of topsoil. The topsoil was used to construct contour banks above the plot areas to prevent any up-slope overland flow from running onto the plots. The experimental area was scarified then rotary hoed (0-10cm) to loosen the exposed B horizon and simulate the condition of the soil surface between the ripped mounds at the HNCMA rehabilitation sites (Figure 21). Runoff plots (5m long x 3 m wide) were established following the experimental protocol described by Wong *et al.* (2005).

Figure 22. Area of CROA where vegetation and topsoil has been removed in preparation for the establishment of runoff plots (Blocks 2-4).

Figure 23. Area of CROA where vegetation and topsoil has been removed in preparation for the establishment of runoff plots (Block 1). Note the proximity to Blocks 2-4 and previous runoff plots established at the site.

3.2.2 Treatments

Six treatments were used:

1. Bare earth control: scarifying + harrowing only
2. Aquatic weed compost (AWC) @ 20 mm depth: scarifying + harrowing followed by surface application of AWC.
3. Soil conditioner @ 16mm + Mulch @ 24 mm (40 mm total depth): scarifying, soil conditioner application + harrowing followed by application of surface mulch.
4. 40/60 Blended Soil Conditioner/ Mulch @ 40 mm: scarifying + harrowing followed by surface application of 40/60 Blend.
5. Soil conditioner @ 8 mm + Mulch @ 12 mm (20 mm total depth): scarifying + soil conditioner application + harrowing followed by application of surface mulch. (i.e. half rate of Treatment 3).
6. 40/60 Blended Soil Conditioner/ Mulch @ 20 mm: scarifying + harrowing followed by surface application of 40/60 Blend. (i.e. half rate of Treatment 4).

Each treatment was replicated four times following a Randomised Complete Block Design, making 24 plots in total (Figure 24).

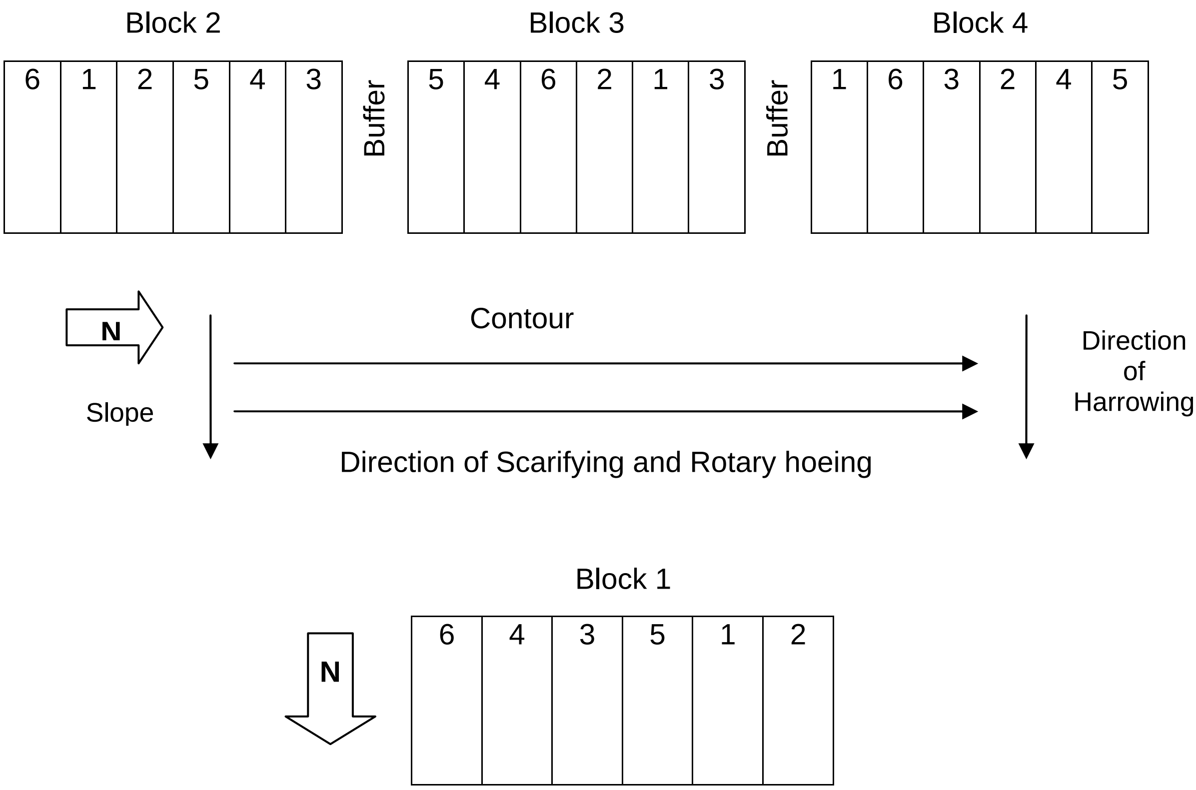

Figure 24. Schematic representation of the layout and randomisation of runoff plots at CROA.

The rotary hoeing and scarifying was performed parallel to the contour (Figure 24) as per normal practice. Harrowing was conducted using a 2m wide set of harrows with a diamond configuration attached to a tractor's front-end loader (bucket removed). The harrowing was conducted down the slope (Figure 24) to avoid inadvertently transporting treatments and soil into adjacent plots.

3.2.3 Soil Sampling

The experimental soil was characterised by collecting 12 cores (0-10cm) per experimental block and bulked to form a composite sample prior to treatment applications and the rainfall simulations. The samples were air dried, ground to pass through a 2mm sieve and chemically analysed for a suite of parameters including pH, electrical conductivity (EC), carbon, nitrogen (N), phosphorus (P), sulfur (S) and exchangeable cations. Total carbon and nitrogen were determined using the Dumas dry combustion method (Horneck and Miller 1996), whilst organic carbon was determined following Walkley and Black (1934). Exchangeable cations were determined using the method of Gillman and Sumpter (1986), whilst pH, EC, and Bray1-P were determined following Rayment and Higginson (1992). KCl-S was determined following Blair *et al.*, 1992, whilst total P and S were determined following USEPA (1996). In addition, soil bulk density (ρ) was also determined on the samples (g/m^3 soil) for subsequent mass balance calculations (Table 10).

Table 10. Selected physical and chemical characteristics of the soil where the runoff plots were established at CROA.

Parameter	Mean ± s.e.
Moisture (%)	8.4 ± 0.3
Bulk density (g/cm^3)	1.4 ± 0.1
$pH_{1:5}$ (H_20)	6.4 ± 0.3
$pH_{1:5}$ ($CaCl_2$)	5.4 ± 0.3
Colwell P (mg/kg)	7.8 ± 1.9
EC (dS/m)	0.13 ± 0.05
Total N (%)	0.1 ± 0.0
Total S (%)	0.01 ± 0.00
KCl-S (mg/kg)	25 ± 8
Carbon (%)	0.6 ± 0.1
Organic carbon (%)	0.6 ± 0.1
Total P %	0.01 ± 0.00
NO_3^--N (mg/kg)	2.0 ± 0.7
Exch. Al ($cmol_c$/kg)	0.2 ± 0.1
Exch. Ca ($cmol_c$/kg)	7.3 ± 0.5
Exch. K ($cmol_c$/kg)	0.6 ± 0.1
Exch. Mg ($cmol_c$/kg)	11.5 ± 1.8
Exch. Na ($cmol_c$/kg)	1.2 ± 0.4
CEC ($cmol_c$/kg)	20.6 ± 1.9

3.2.4 Compost collection and characterisation

The aquatic weed compost was collected from the composted windrows at Hawkesbury City Council Waste Management Facility (HCCWMF). It was not subjected to screening or further processing. The composted garden organics soil conditioner and mulch were purchased from a commercial composting facility within the Sydney Region. The composted garden organics were principally derived from garden organics and did not contain any other recycled organics, such as poultry litter, biosolids or cattle manure.

Samples of the aquatic weed compost (AWC), composted garden organics soil conditioner and composted garden organics mulch were collected and analysed for a range of physical, chemical and biological characteristics following the procedure described in Section 2.2.3. Five, three and three composite AWC compost, soil conditioner and mulch samples were analysed, respectively (Table 11-13). The results for each parameter were compared against the limits defined in (Standards Australia 2003) and the draft compost specifications developed by the DECC and HNCMA. Particular parameters of interest included nutrients, heavy metals and pesticide residues.

The composted soil conditioner complied with the specified limits for all parameters tested with the exception of Zinc, which was above the Grade A limit for unrestricted use of 200 mg/kg, but within the 700 mg/kg limit for Grade B products (Table 13). The composted mulch complied with the specified limits for all parameters tested with the exception of light plastics >5mm (≤ 0.05%) (Table 12). However, it did not meet the more restrictive limits for Glass, metal and rigid plastics > 2mm and light plastics >5mm (≤ 0.05% and ≤0.005%, respectively) proposed in Dorahy *et al.* (2007) for composted mulches used for catchment rehabilitation works (Table 12).

Table 11. Chemical characteristics of composted aquatic weed (AWC), garden organics soil conditioner (SC) and mulches used in the rainfall simulations.

Parameter	AWC	SC	Mulch
	-----------------	Mean (± s.e)	----------------
pH	7.2 ± 0.0	7.1 ± 0.1	7.0 ± 0.0
EC (dS/m)	2.2 ± 0.2	3.0 ± 0.0	2.3 ± 0.0
Soluble P (mg/L)	0.4 ± 0.1	3.2 ± 0.4	0.7 ± 0.1
Total P (%)	0.08 ± 0.01	0.23 ± 0.0	0.06 ± 0.0
NH_4^+-N	0.7 ± 0.2	2.7 ± 1.7	8.2 ± 1.3
NO_3^--N	26.4 ± 2.9	0.0 ± 0.0	0.1 ± 0.1
NH_4^+-N + NO_3^--N	26.6 ± 2.9	2.8 ± 1.8	8.3 ± 1.2
Total N (%)	0.6 ± 0.1	1.2 ± 0.0	0.6 ± 0.0
Organic matter (LOI) (%)	19.6 ± 1.1	50.3 ± 0.1	90.4 ± 0.5
Boron (mg/kg)	18.3 ± 9.0	21.7 ± 0.3	26.0 ± 1.0
Sodium (%)	0.1 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
Calcium (%)	0.6 ± 0.1	1.6 ± 0.1	0.9 ± 0.1
Magnesium (%)	0.2 ± 0.0	0.3 ± 0.0	0.2 ± 0.0

Table 12. Physical and biological characteristics of composted aquatic weed (AWC), garden organics soil conditioner (SC) and mulches used in the rainfall simulations.

Parameter	AWC	SC	Mulch
	-----------------	Mean (± s.e)	----------------
Physical characteristics			
Moisture content (%)	25.2 ± 2.0	36.3 ± 1.5	21.0 ± 1.7
Density (kg/m^3)	773 ± 0	537 ± 12	232 ± 4
Wettability (min)	6.6 ± 1.4	6.5 ± 0.9	0.2 ± 0.0
Particle size < 15mm (%)	94.5 ± 1.2	99.6 ± 0.2	32.6 ± 2.6
Particles > 15mm (%)	5.5 ± 1.2	0.4 ± 0.2	69.3 ± 2.6
Glass, metal, rigid plastics (>2mm) (%)	0.2 ± 0.1	0.0 ± 0.0	0.3 ± 0.2
Light plastic > 5mm (%)	0.04 ± 0.02	0.0 ± 0.0	0.1 ± 0.0
Stones and lumps of clay > 5mm (%)	6.8 ± 0.7	4.0 ± 0.2	1.6 ± 0.2
Biological characteristics			
Toxicity index (mm)	96.9 ± 7.7	74.9 ± 3.6	na

Table 13. Heavy metal and organic contaminant concentrations (mg/kg) in composted aquatic weed (AWC), garden organics soil conditioner (SC) and mulches used in the rainfall simulations.

Parameter	AWC	SC	Mulch
	--------------Mean (± s.e)-------------		
Heavy metals (mg/kg)			
Arsenic	9 ± 1	17 ± 0	16 ± 3
Cadmium	<1.0	<1.0	<1.0
Chromium	18 ± 2	47 ± 20	29 ± 5
Copper	27 ±2	96 ± 17	28 ± 2
Lead	63 ±4	107 ± 3	30 ± 1
Mercury	<0.1	<1.0	<1.0
Nickel	9 ±1	10 ± 0	3 ± 1
Selenium	<3.0	<3.0	<3.0
Zinc	198 ± 30	247 ± 3	84 ± 4
Organics (mg/kg)			
DDT/ DDD/ DDE	<0.02	<0.02	<0.02
Aldrin	<0.02	<0.02	<0.02
Dieldrin	<0.02	<0.02	<0.02
Chlordane	<0.02	<0.02	<0.02
Heptachlor	<0.02	<0.02	<0.02
HCB	<0.02	<0.02	<0.02
Lindane	<0.02	<0.02	<0.02
BHC	<0.02	<0.02	<0.02
PCBs	<0.1	<0.1	<0.1

3.2.5 Treatment application

The bulk density of each material was used to determine the loading required on each runoff plot to achieve the desired application depth and subsequent mass balance calculations. Each product was weighed into garbage bins and placed into a front end loader for transport and application to each plot. Once applied, it was raked to achieve a uniform distribution across the plot.

Calculations regarding the amount of each treatment required are summarised in Table 13. This assumes that 50 mm of mulch corresponds to an application rate of 500m^3/ha; each plot was 15 m^2 (0.0015 ha); with each treatment replicated 4 times.

Table 14. Summary of the quantity of material required to achieve the desired application depth of aquatic weed compost (AWC), composted garden organics soil conditioner (SC) and composted garden organics mulch to experimental runoff plots at CROA.

Treatment	Depth -----------(mm)-----------			Application rate ---------(m^3/plot)-------			Total load required -----------(m^3)-----------		
	AWC	SC	Mulch	AWC	SC	Mulch	AWC	SC	Mulch
1. Bare earth control	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0
2. AWC @ 20mm	20	0	0	0.3	0.0	0.0	1.2	0.0	0.0
3. SC incorp @ 16 mm + mulch @ 24 mm	0	16	24	0.0	0.2	0.4	0.0	1.0	1.4
4. 40/60 blend surface applied @ 40 mm	0	16	24	0.0	0.2	0.4	0.0	1.0	1.4
5. SC incorp @ 8 mm + mulch @ 12 mm	0	8	12	0.0	0.1	0.2	0.0	0.5	0.7
6. 40/60 blend surface applied @ 20 mm	0	8	12	0.0	0.1	0.2	0.0	0.5	0.7
Total of each product	20	48	72	0.3	0.7	1.1	1.2	2.9	4.3

3.2.6 Rainfall simulations

A rainfall simulator was used to deliver 67mm/hr for a 30 minute period i.e. the equivalent of a 1 in 10 year rainfall event, (Wong *et al.*, 2005) to a 0.75m x 2.0 m area within the experimental plots (Figure 25), Simulations were completed within two months of treatment application as this is the period when exposed soil is most vulnerable to erosion.

During simulations the volume and rate of runoff was recorded allowing an evaluation of the effectiveness of the six treatments in reducing surface runoff. The entire runoff volume from each simulation was collected in a cylindrical container (TED) samples were taken for analysis.

Two assessments of water quality were undertaken, namely first flush and total load, following the procedure described by Eldridge (2005).

A first flush sample was taken by collecting the first 3L of runoff. One litre of this was sub-sampled for analysis with the remaining 2L returned to the TED. Before the unused first flush sample was returned to the TED, the TED's contents were mixed and a proportion of the runoff in the TED was decanted to ensure the original ratio of first flush volume: total runoff volume was retained. Once the remaining first flush sample was returned to the TED, the total combined volume was thoroughly mixed before a total load runoff sample (1L) was collected for analysis and a 500mL sample was collected for archives.

Runoff samples were stored at 4ºC until they were couriered in cooled insulated containers to laboratories for analysis. Total suspended solids (TSS) (APHA 2540D), total dissolved solids (TDS) (APHA 2540C), total organic carbon (TOC) (APHA 5310), dissolved organic carbon (DOC) (APHA 5310), total nitrogen, ammonia-N and nitrate-N (APHA 4500NO3), total phosphorus (TP) and Free Reactive P (FRP) (APHA 4500P), turbidity (APHA 2130), and total dissolved solids (TDS) in the samples were determined at the NSW DPI's Analytical Laboratories at Wollongbar, NSW using the methods described by (APHA, 1995). A sub-sample (500mL) of the runoff from each plot was frozen and analysed for Biochemical Oxygen Demand (BOD) at Envirocheck Laboratories, Campbelltown, using the APHA 5210B (APHA, 1995).

The sediment and nutrient concentrations (mg/L) in the total event sample were multiplied by the total runoff volume to calculate the total load of sediment and nutrients exported from each plot as a consequence of treatment application and the 1 in 10 year rainfall event.

Figure 25. Illustration of the rainfall simulator used to deliver a 1 in 10 year rainfall event to runoff plots as part of the experiment.

3.2.7 Ground cover and vegetation assessments

Prior to the addition of the compost treatments, a pasture/fertiliser mix was applied to the plots at a rate of 21.5 kg seed /ha and 20 kg fertiliser/ha (Granulock 15 (N:P:K:S = 14:12:0:11). The composition of the pasture seed mix is summarised in Table 16. This pasture/fertiliser mix is used by the Hawkesbury-Nepean Catchment Management Authority in their catchment rehabilitation works and enabled the effect of each treatment on pasture emergence and establishment to be determined.

Table 15. Pasture species and fertiliser applied to runoff plots as seed prior to the application of composted soil conditioners and/ or mulches.

Common name	Botanical name
Goulburn Sub clover	*Trifolium subterraneum* cv. Goulburn
Dixie Crimson clover	*Trifolium incarnatum* cv. Dixie
Seaton Park clover	*Trifolium subterraneum* cv. Seaton Park
Haifa white clover	*Trifolium repens* cv. Haifa
Tahora white clover	*Trifolium repens* cv. Tahora
Meridian Rye clover	*Lolium perenne* cv. Meridian
Australian II Phalaris	*Phalaris aquatica* cv. Australian II
Vic Rye	*Lolium perenne* cv. Victoria
Kingston Rye	*Lolium perenne* cv. Kingston
Currie Cocksfoot	*Dactylis glomerate* cv. Currie
Rye Corn	*Secale cereale*

Ground cover assessments of the experimental plots were performed to measure the short term treatment effects on vegetation establishment, as well as determine whether any Alligator Weed was present. The assessments were performed by visually assessing 4 x 30cm^2 areas at random within each plot and estimating percentage ground cover.

Vegetation cuts were undertaken 6 and 12 weeks after the rainfall simulations were completed. Two x 30cm^2 quadrats were cut at random from within each plot using secateurs and placed in brown paper bags for weighing. The pasture fresh weights were recorded and the samples were dried at 70°C for 48hrs in an oven to enable determination of moisture content and dry matter production of the pastures in each plot.

3.2.8 <u>Nutrient loadings</u>

The nutrient concentrations (Table 11), moisture content and density (Table 12) and application rates (Table 14) of the AWC and composted soil conditioners and mulches were used to calculate the nitrogen and phosphorus loadings associated with each of the treatments. It should be noted that in the 20mm and 40 mm "Blend" and "Incorp" treatments there were two sources of nutrients, namely the composted soil conditioners and composted mulches. These sources were taken into account in each of the respective calculations. The N and P loadings from the application of fertiliser in all treatments (Section 3.2.8) were also taken into account. The method for calculating these is summarised in Table 16.

Table 16. Summary of the method used to calculate nitrogen and phosphorus loadings associated with each of the treatments used in the rainfall simulations.

Code	Parameter	Formula/ Source
A	Concentration (%)	Table 11
B	Moisture content (%)	Table 12
C	Density (kg/m^3)	Table 12
D	Application rate (mm)	Table 14
E	Application rate (m^3/ha) (D*10)	D*10
F	Application rate (product kg/ha) (C*E)	C*E
G	Application rate (dry kg/ha)	F*(1-(B/100))
H	Nutrient loading from soil conditioner and/or mulch (kg/ha)	A/100*G
I	Nutrients from fertiliser application (kg/ha)	Section 3.2.7
	Total (kg/ha) (SC + Mulch + Fertiliser)	H + I

3.2.9 <u>Statistical analysis</u>

The results from the rainfall simulations and ground cover assessments were analysed using analysis of variance (ANOVA) in the R statistical program (The R Core Development Team 2005). This assumed variance was normally distributed. Treatments effects were deemed to be statistically significant at the 5% level of probability ($P<0.05$). Least squares difference (lsd) was calculated to compare treatment means when $P<0.05$.

3.3 Results

3.3.1 <u>Rainfall simulations</u>

<u>Runoff</u>

None of the treatments had any significant effect on the time to runoff, time to capture 3L of runoff, runoff duration or total runoff volume (Figure 26). However, there was a trend for the time between the start of the rainfall simulation and runoff from the plots to increase with application depth (Figure 26).

Nitrogen

Total nitrogen concentrations in both the first flush and final runoff samples were significantly higher in the aquatic weed compost treatment when compared to the bare earth control (Figure 27). However, the concentrations of soluble N, namely filtered, ammonium and nitrate in the runoff samples from the aquatic weed compost were not significantly higher than the control (Figure 27). Nitrate concentrations in the AWC treatment were however, significantly higher than the other compost treatments (Figure 27).

The concentrations of filtered N and ammonium in the 40mm treatments depths were significantly higher than the control and other treatments (Figure 27). However, the incorporation of 16mm of soil conditioner followed by the application of a 24mm mulch blanket (40mm Incorp), significantly reduced nitrate concentrations in runoff relative to the control and AWC treatments (Figure 27). Moreover, the concentrations of total and filtered N in the final runoff samples from the 40mm Incorp treatment were significantly lower than those where a 40/60 soil conditioner/mulch blend had been surface applied to a depth of 40mm (40mm Blend) (Figure 27).

Phosphorus

Total P concentrations in the first flush and final runoff samples were significantly higher in the AWC, 20mm Blend and 40mm treatments relative to the bare earth control (Figure 28). Filtered P and Free reactive P concentrations in the first flush and runoff samples were significantly higher in the 40mm treatments relative to the bare earth control and other treatments (Figure 28).

The incorporation of 16mm of soil conditioner followed by the application of a 24mm mulch blanket (40mm Incorp) resulted in significantly lower concentrations of total, filtered and free reactive P in the runoff, relative to the surface application of a 40/60 soil conditioner/ mulch blend to a depth of 40mm (40mm Blend) (Figure 28).

Carbon and BOD

The concentrations of dissolved and total organic carbon in the runoff from the first flush and final water samples in the bare earth control, AWC and 20mm Incorp treatments were significantly lower than those in the 20mm Blend and 40mm treatments (Figure 29).

The incorporation of 16mm of soil conditioner followed by the application of a 24mm mulch blanket (40mm Incorp) resulted in significantly lower concentrations of dissolved and total organic carbon in the runoff, relative to the surface application of a 40/60 soil conditioner/ mulch blend to a depth of 40mm (40mm Blend) (Figure 29).

Biochemical oxygen demand (BOD) concentrations in the total runoff from both of the 40mm application depths were significantly higher than the other treatments (Figure 29).

Sediments and salts

The turbidity and concentrations of total suspended solids in the runoff from the control and aquatic weed compost treatments were significantly higher than those from the 20mm and 40mm treatments (Figure 30). In addition, the total suspended sediment concentrations in the first flush runoff sample from the 40 mm treatments were significantly lower than those from the 20mm treatments (Figure 30).

The concentrations of total dissolved solids in the Control, AWC and 20mm Incorp treatments were significantly lower than those in the 20mm Blend and 40mm treatments (Figure 30).

<u>Sediment and nutrient export</u>

The application of compost prepared from harvested aquatic weed (AWC) significantly reduced the export of suspended solids from the plots, relative to the control by 34% (Figure 30). However, the magnitude of the reduction was not as large as that observed from the 20mm and 40mm treatments (Figure 31), which was in the order of >70% and 91%. Surface application of a 40/60 soil conditioner/mulch blend to a depth of 40mm (40mm Blend) significantly increased total P export, relative to the other treatments (Figure 31). Total nitrogen export from the AWC treatment was significantly higher than the control, equivalent to the 20mm and 40mm Incorp treatments but lower than the 40mm Blend treatment (Figure 31).

The incorporation of 16mm of soil conditioner followed by the application of a 24mm mulch blanket (40mm Incorp) resulted in significantly lower export of total nitrogen from the plots, relative to the surface application of a 40/60 soil conditioner/mulch blend to a depth of 40 mm (40mm Blend) (Figure 31).

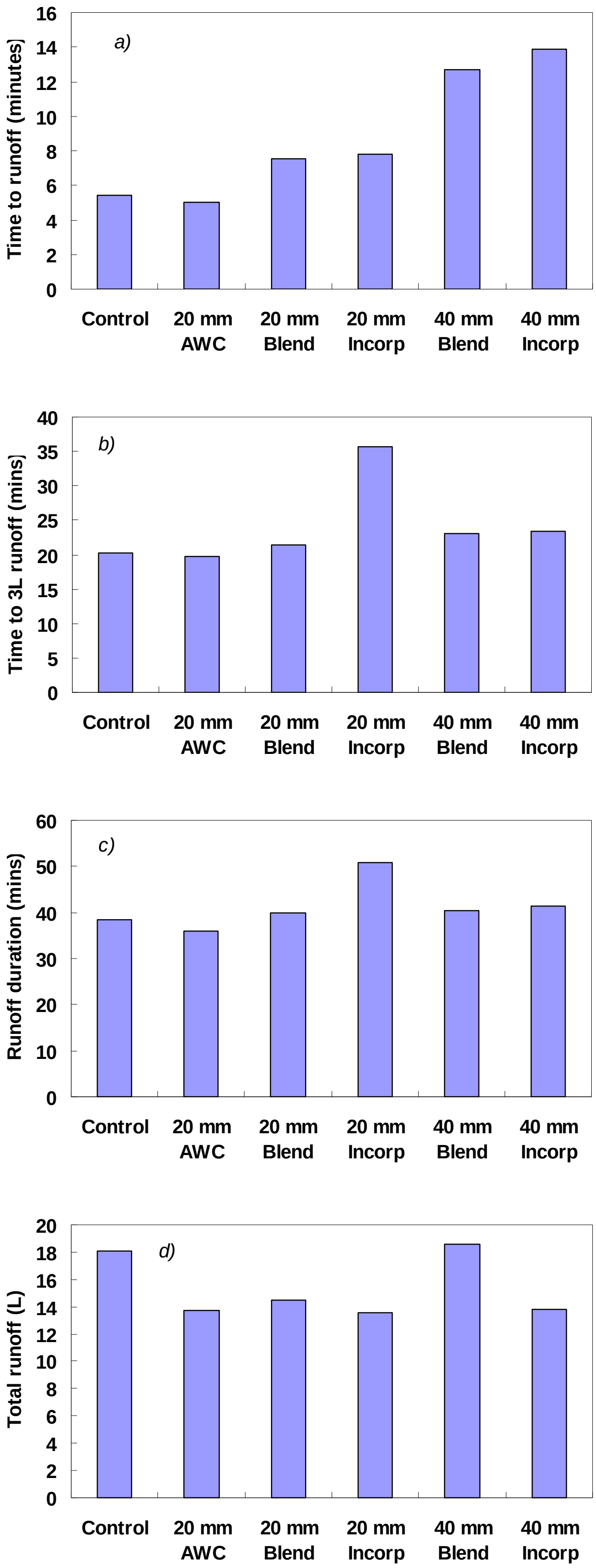

Figure 26. Effect of compost type, application depth and method of application on a) time to runoff; b) time to capture 3L of runoff (mins); c) runoff duration (mins); and d) total runoff

volume (L) captured from a 1 in 10 year simulated rainfall event. (No lsd bars are presented because treatment differences were not significant at *P*<0.05).

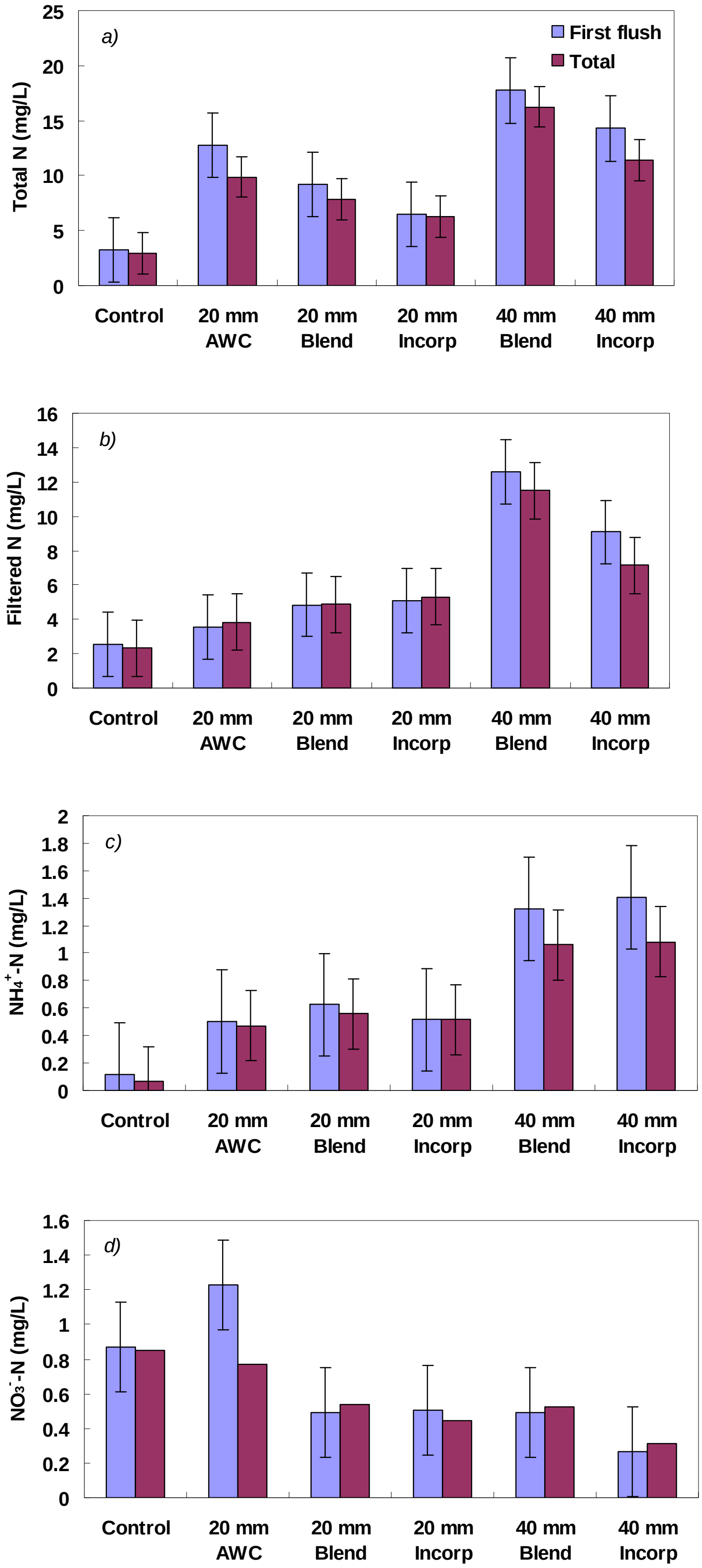

Figure 27. Effect of compost type, application depth and method of application on a) total N; b) filtered N; c) ammonium (NH_4^+-N); and d) nitrate (NO_3^--N) concentrations (mg/L) in runoff from a 1 in 10 year simulated rainfall event. Vertical bars represent the least squares difference at the *P*<0.05 level of significance.

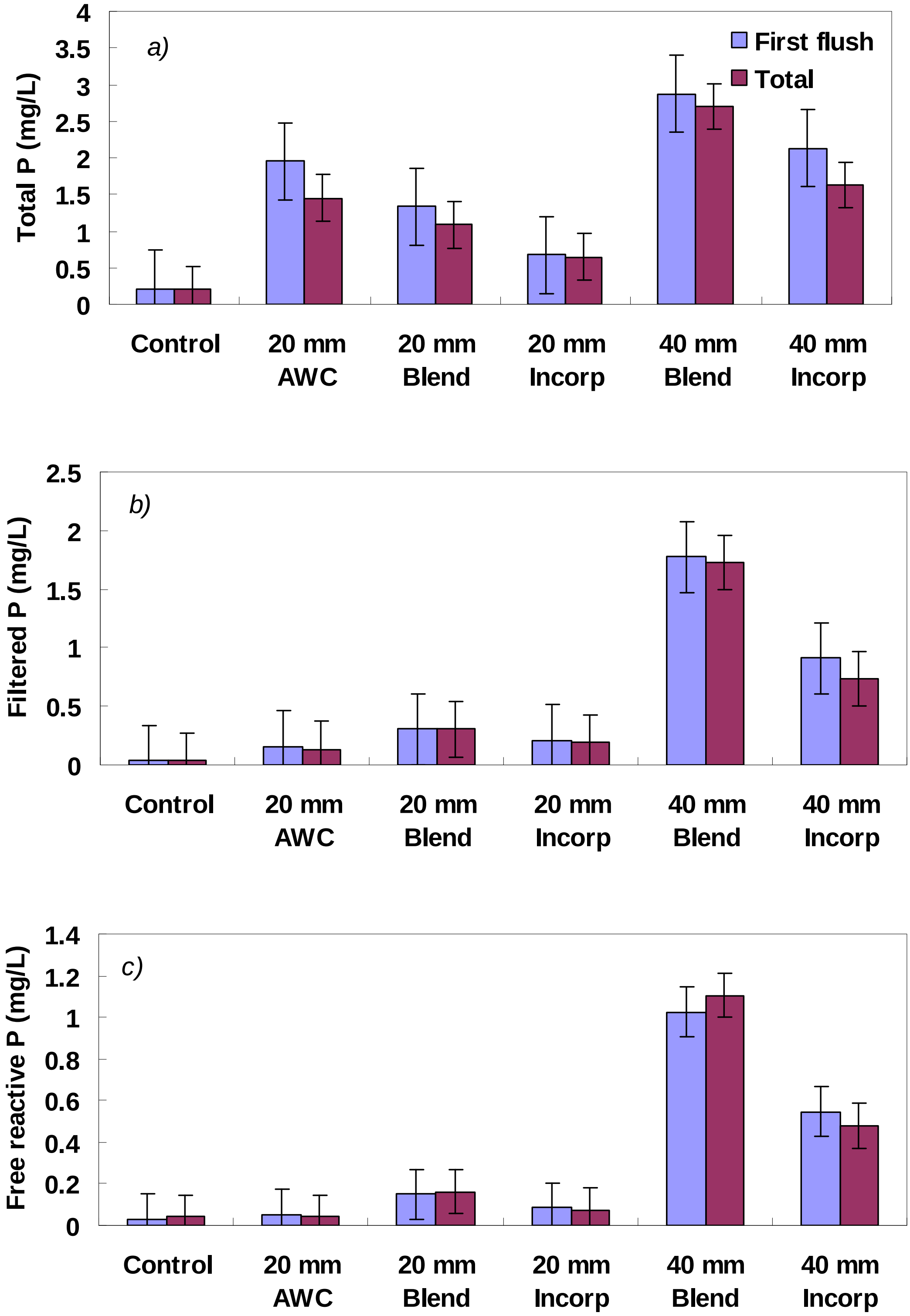

Figure 28. Effect of compost type, application depth and method of application on a) total P; b) filtered P; and c) free reactive P concentrations (mg/L) in runoff from a 1 in 10 year simulated rainfall event. Vertical bars represent the least squares difference at the *P*<0.05 level of significance.

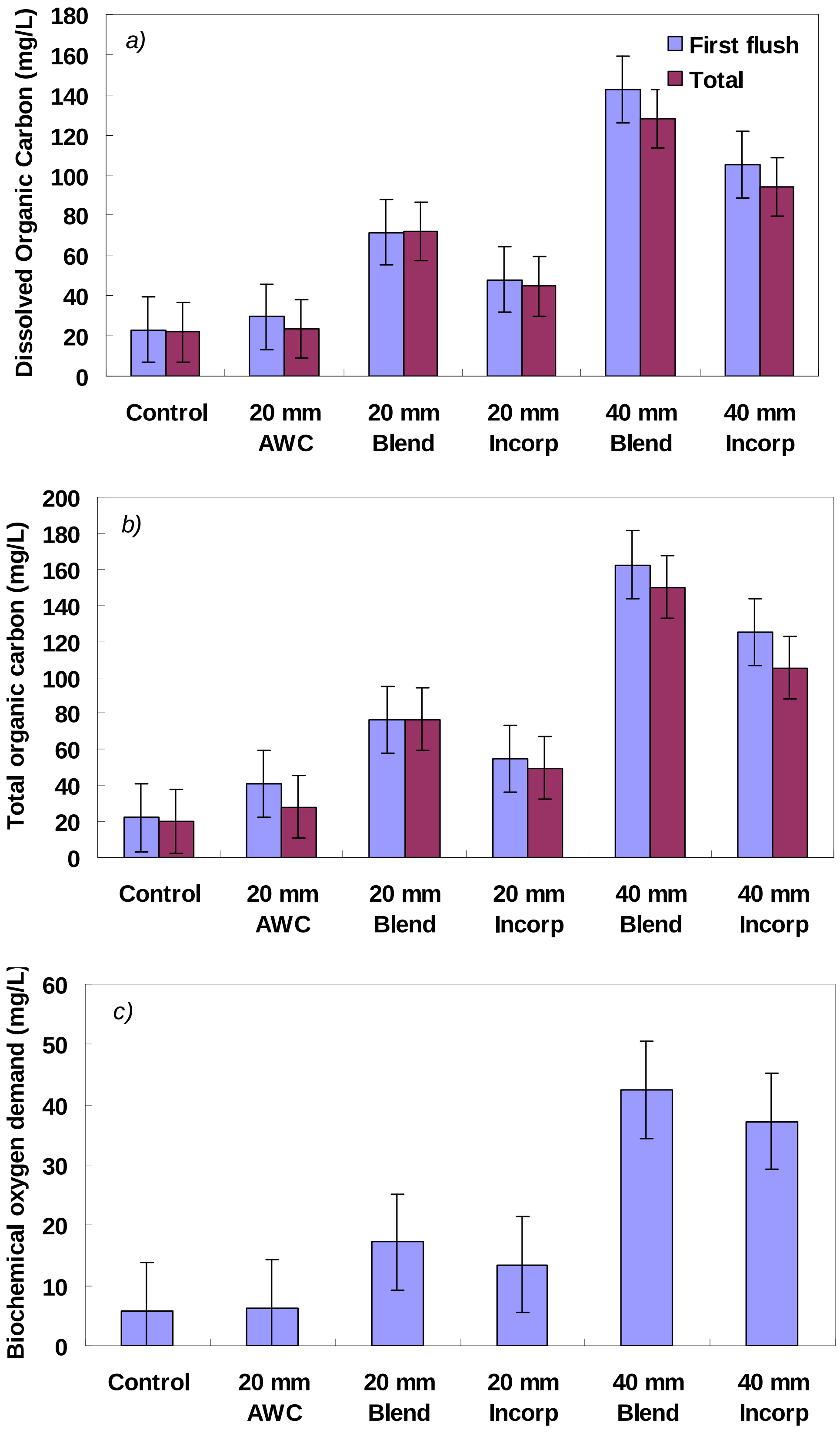

Figure 29. Effect of compost type, application depth and method of application on a) dissolved organic carbon; b) total organic carbon and c) biochemical oxygen demand concentrations (mg/L) in runoff from a 1 in 10 year simulated rainfall event. Vertical bars represent the least squares difference at the *P*<0.05 level of significance.

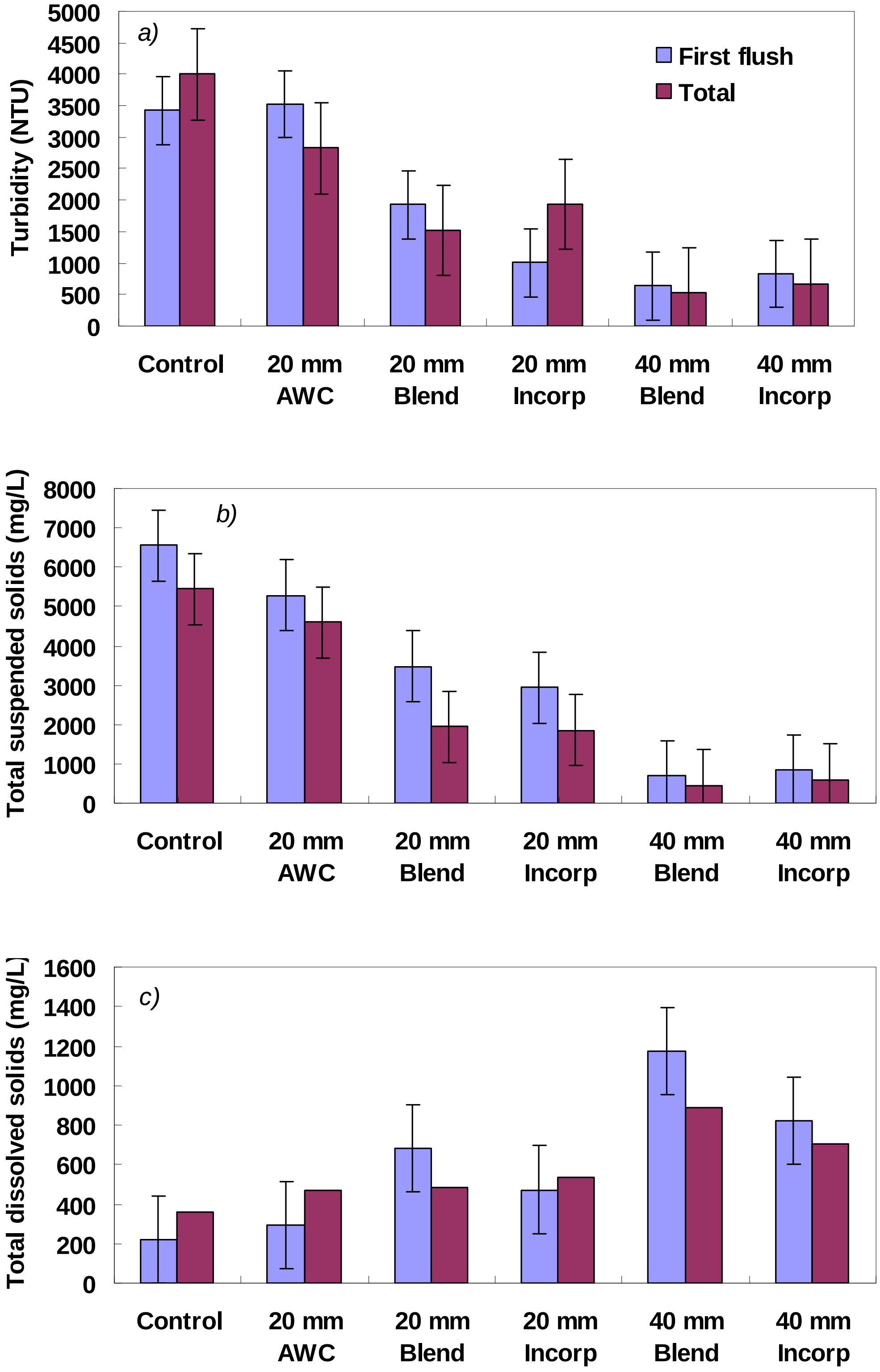

Figure 30. Effect of compost type, application depth and method of application on a) turbidity (NTU); b) total suspended solids; and c) total dissolved solids concentrations (mg/L) in runoff from a 1 in 10 year simulated rainfall event. Vertical bars represent the least squares difference at the *P*<0.05 level of significance.

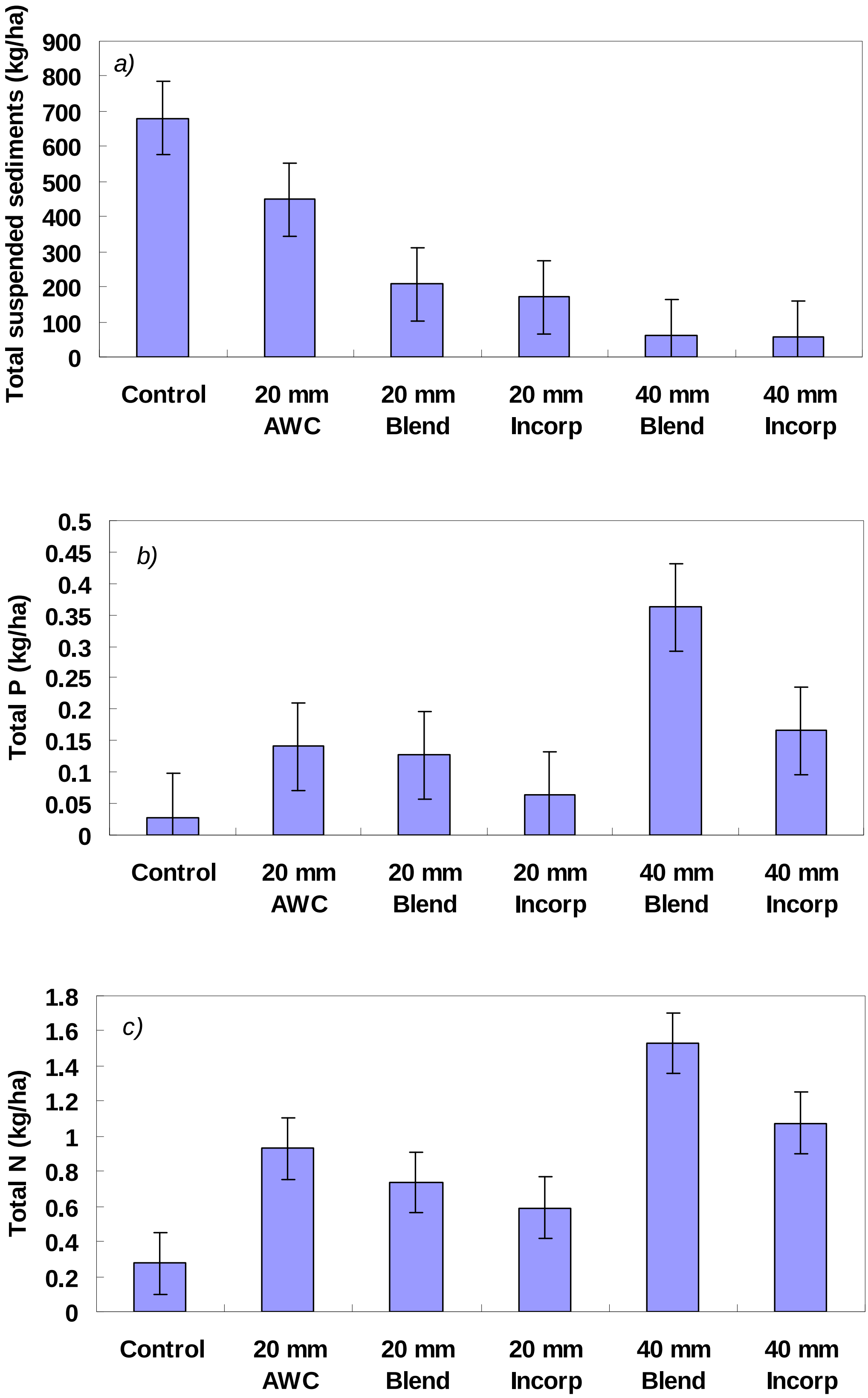

Figure 31. Effect of compost type, application depth and method of application on loads (kg/ha) of a) total suspended sediments; b) total P; and c) total N exported in runoff from a 1 in 10 year simulated rainfall event. Vertical bars represent the least squares difference at the $P<0.05$ level of significance.

3.3.2 Groundcover assessments and pasture production

The AWC and 20mm Blend treatments had significantly higher vegetative ground cover than the bare earth control (Figure 32). The effect of the 20mm Incorp and 40mm application treatments was not significant, relative to the bare earth control. One important observation from the ground cover assessments was that no alligator weed was detected in the plots where compost prepared from harvested aquatic weed (AWC) had been applied.

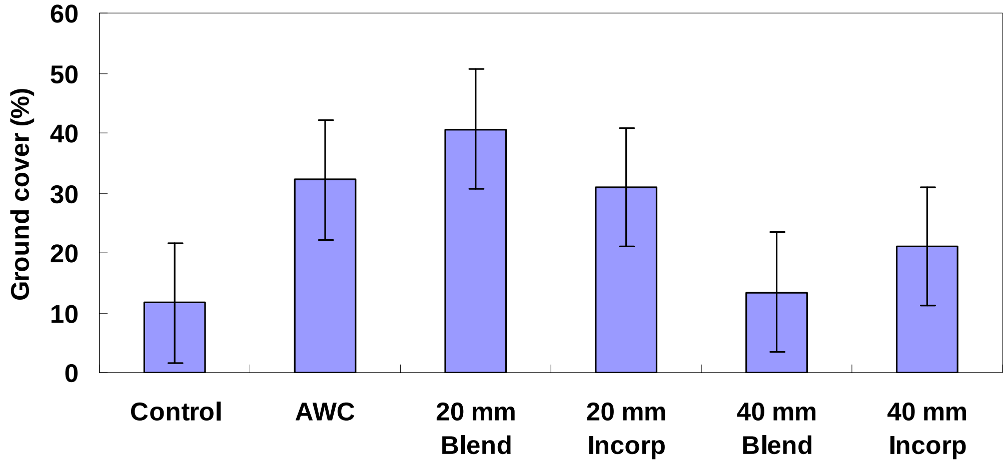

Figure 32. Effect of compost type, application depth and method of application on ground cover (%) 6 weeks after rainfall simulations were completed. Vertical bars represent the least squares difference at the *P*<0.05 level of significance.

No significant treatment effects were detected in the pasture cuts collected 6 weeks after the rainfall simulations had been completed (Figure 33). However, by 12 weeks, pasture dry matter production in the plots treated with AWC was significantly higher than all of the other treatments (Figure 33). Pasture dry matter production in the 40 mm Incorp treatment was the only other treatment, which was significantly higher than the bare earth control (Figure 33).

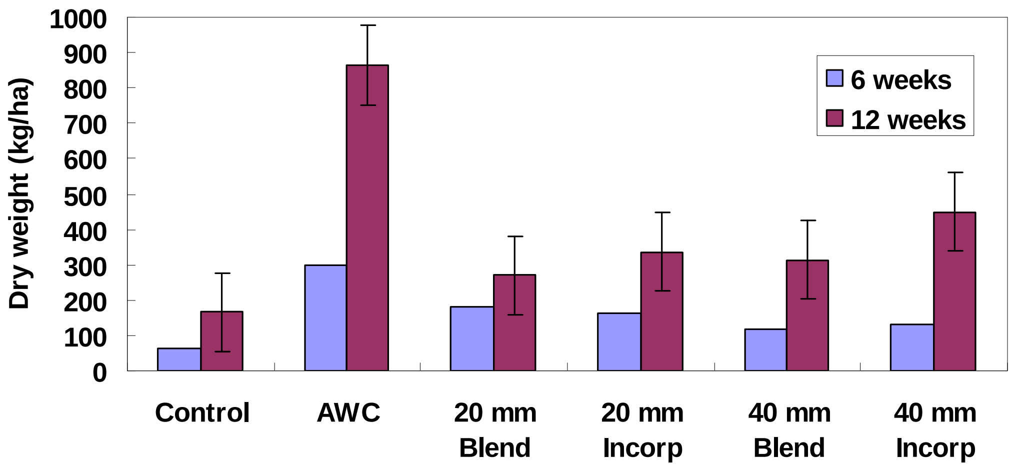

Figure 33. Effect of compost type, application depth and method of application on pasture dry matter production (kg/ha) 6 and 12 weeks after rainfall simulations were completed. Vertical bars represent the least squares difference at the *P*<0.05 level of significance.

Nutrient loadings

The nitrogen and phosphorus loading in the bare earth control, as a consequence of fertiliser applied in conjunction with the pasture seed were 2.8 and 2.4 kg/ha, respectively (Table 17). The nitrogen and phosphorus loadings from the compost prepared from harvested aquatic weed (AWC) , the 20 mm and 40 mm depth treatments were 699 and 95, 466 and 79, 928 and 155 kg/ha, respectively (Table 17).

Table 17. Summary of the nitrogen (N) and phosphorus (P) loadings associated with each of the treatments in the rainfall simulation study.

Treatment	N	P
	---- (kg/ha) ----	
Bare earth control	2.8	2.4
AWC	699	95
20 mm Blend	466	79
20 mm Incorp	466	79
40 mm Blend	928	155
40 mm Incorp	928	155

3.4 Discussion

Performance of AWC

The composted soil conditioner prepared from harvested aquatic weed (AWC) significantly increased vegetative ground cover and pasture dry matter production relative to the bare earth control and some of the other soil conditioner/ mulch treatments (Figures 32 and 33). This indicates it is beneficial as a growing medium for establishing pastures, particularly in areas of catchments, which are denuded of topsoil. In addition, applying the compost at a depth of 20 mm would provide considerable quantities of nitrogen and phosphorus (699 and 95 kg/ha, respectively). As these nutrients mineralise over time, they would be expected to provide significant benefits in terms of improved soil fertility and plant nutrition.

The results from the rainfall simulations indicate that compost prepared from harvested aquatic weed (AWC) has the potential to reduce the load of sediment exported in runoff from exposed soil (Figure 30). However, it was less effective than the other compost treatments evaluated in reducing sediment transport. This is attributed to the small proportion (5.5%) of particles >15 mm in size (Table 12) in the aquatic weed compost, which could entrain particles in the runoff. It is these larger particles that physically shield the soil surface, dissipate energy from raindrop impact and help trap entrained soil particles (Adam 1966; Agassi *et al*., 1998, Wong and Malik, 2004). In contrast the 20 and 40mm treatments contained 60% mulch which is dominated by coarse particles (Table 12) and explains why these treatments reduced sediment export by 70-90% (Figure 30). This highlights the importance of groundcover in reducing the potential for sediment export and subsequent impacts on water quality.

Given the AWC was characterised by fine particles (Table 12), there is potential for it to be mobile in windy conditions. This was highlighted by Wong *et al.* (2005) who found the erosion control performance of applying soil conditioners alone to a windy site near Bungonia in south-west NSW was reduced due to the fine particles being blown away. Therefore, composted soil conditioners should be incorporated into the soil after application, blended or applied in conjunction with coarse mulches, particularly in windy or exposed sites.

Application depth

Generally, increasing the depth of application from 20 to 40mm increased the concentrations of most water quality parameters measured, in particular total N (Figure 26), total P, filtered P and free reactive P (Figure 27), organic carbon and BOD (Figure 28). This would be expected given the higher nutrient and organic matter loadings associated with the higher application rates (Table 14). Whilst increased application depths (40 mm) decreased the turbidity and suspended solids concentrations in the runoff, they did not significantly reduce the sediment loads exported relative to the 20mm depth treatments. Therefore, it can be suggested that applying the composted products at a depth of 20mm provides equivalent erosion control performance to the 40mm treatments but does not increase the rate of nutrient export beyond that which would be expected from exposed soil.

As vegetative cover of the soil surface is the most effective form of erosion control (Loch 2000; Storey *et al*. 1996) the effect of each treatment on plant growth and establishment is critical to long term site stabilisation. The highest proportion of ground cover was achieved in the treatments where the composted soil conditioners and/ or mulch were applied at a depth of 20 mm (Figure 32). No significant increase in vegetative cover was observed in the plots where the compost had been applied at depths of 40mm. This is most likely a consequence of the compost, particularly the coarse mulch fraction acting as a physical barrier to seedling emergence. Therefore, the lower application rates (~20mm) may also assist in promoting vegetative cover on degraded sites.

Application method

This research also provided an opportunity to evaluate the methods which have been used to apply composted soil conditioners and mulches to large scale demonstration sites in the Hawkesbury-Nepean Catchment. No significant differences in the water quality parameters evaluated were observed between application methods where the compost treatments were applied at a depth of 20mm. However, at the 40mm depths, the incorporation of 16mm of soil conditioner followed by the application of a 24mm mulch blanket resulted in significantly lower concentrations of nitrogen, phosphorus, organic carbon in the runoff, relative to the surface application of a 40/60 soil conditioner/mulch blend (Figures 26-31). Similarly, less nitrogen and phosphorus was exported from the 40mm Incorp plots relative to those which were treated with the 40mm Blend.

Therefore it can be suggested that at low rates (~20mm depth), application method does not significantly influence the performance of the composted mulches and soil conditioners. However, at higher application rates (~40mm) runoff water quality is improved and the potential for nutrient export is reduced when the soil conditioner is incorporated and is followed by the broadcast application of coarse mulch.

Performance of recycled organics in reducing runoff

Adams (1966) and De Vleeschauwer and Lal (1978) found mulch application increased the rate of water infiltration and the amount of water stored in the soil profile, which resulted in less runoff. However, our results were inconclusive with respect to the ability of compost prepared from harvested aquatic weed and source separated garden organics to reduce runoff. Similarly, Wong *et al.* (2005) did not find any significant reduction in runoff volumes in experimental plots at Camden (CROA) and Bungonia treated with cereal straw, composted soil conditioners and mulches, relative to bare earth controls.

There was a large amount of variability associated with our runoff measurements, making it difficult to detect statistical differences between the treatments. Heterogeneity in soil moisture content and bulk density across the plots may have affected the infiltration rates and subsequent runoff, in addition to the experimental treatments. However, the sensitivities of the analysis of variance models for runoff were not improved even when soil moisture and bulk density were accounted for (data not presented), suggesting runoff was controlled by other factors. The rainfall simulations were performed within 2 months of ripping, cultivation and compost application and so the plots were in a highly disturbed state. Treatment differences may have been more apparent once the soil and compost treatments equilibrated with time. However, the intention of our study was to examine the performance at a time when the soil was most vulnerable to erosion (i.e. when it was in a disturbed state and void of vegetation). Further investigation is required to improve understanding of the potential for composted soil conditioners and mulches to reduce runoff from degraded catchments.

3.5 Conclusions and recommendations

This research demonstrates the potential for compost prepared from aquatic weed compost to be a useful medium for re-establishing vegetation on sites which are denuded of topsoil and act as a considerable source of nitrogen and phosphorus to restore soil fertility and improve plant nutrition. It also has potential to reduce the load of sediment exported from degraded catchments. However, the erosion control performance of compost prepared from harvested aquatic weed could be improved by blending or applying it in conjunction with coarse mulches in the ratio of 40% soil conditioner to 60% coarse mulch.

An application rate, which will achieve a depth of 20mm on the soil surface should provide adequate erosion control, allow decent pasture emergence and minimise the potential for nutrient transport in runoff. At this rate, application method does not appear to influence product performance. However at higher application rates (eg. 40 mm depth), the composted soil conditioner should be incorporated and followed by the application of a mulch blanket, in preference to broadcasting a 40/60 soil conditioner/mulch blend on the soil surface. Though the higher application rates have significantly lower pasture emergence and establishment compared to the 20mm Blend, Incorp or AWC applications.

Further research is required to reduce the variability associated with measuring runoff volumes using rainfall simulators, to elucidate the potential for composted mulches and soil conditioners to reduce runoff in degraded catchments and to ascertain the longer term effects of composted product application on soil structure and infiltrative capacity.

4 GENERAL DISCUSSION

The objectives of this project were to identify the potential benefits and risks associated with using compost prepared from harvested aquatic weed for improving land condition in the Hawkesbury-Nepean Catchment, so that opportunities for beneficially reusing what would otherwise be a "waste" material could be identified.

4.1 Potential risks

The four key risks associated with compost prepared from aquatic weeds removed from waterways are: i) survival and spread of terrestrial and aquatic weeds; ii) eutrophication of waterways; iii) accumulation of heavy metals; and iii) phytotoxicity. These were assessed by undertaking an environmental risk assessment which involved:

- Determining whether the composting process employed destroyed the viability of the harvested aquatic weeds.
- Characterising the chemical, physical and biological characteristics of the composted product.
- Applying the data generated to assess the environmental risk associated with the compost.
- Developing strategies for managing any risks identified.

The potential for aquatic and terrestrial weeds, particularly Alligator weed, to survive the composting process was the main risk identified.

4.1.1 <u>Process evaluation and site monitoring</u>

Process evaluation revealed composting is an effective method of reducing the viability of aquatic and terrestrial weeds. However, weed mortality depends on the temperature within the composting windrows and the length of time the material is subjected to the composting process. Consequently, the composting process must be carried out in accordance with the Australian Standard for composts, mulches and soil conditioners (AS4454) in order to be effective.

Site monitoring revealed some alligator weed growing at the base of the compost windrows and elsewhere on the site. This was attributed to the lack of an appropriate hardstand upon which the compost windrow was established. This meant that not all of the material in the windrow was turned and exposed to the pasteurising conditions (>55^{o}C for three consecutive days) required to destroy any viable weed seeds or plant fragments.

Hence, it is vital check the site regularly for any weeds growing in or around the windrows. If any weeds are detected, composting procedures should be reviewed to identify the cause of the outbreaks and take action to prevent them re-occurring. This closes the loop in the process of undertaking environmental risk assessments given it creates a mechanism for determining whether the risk is acceptable and manageable or whether further work is required to quantify the risk and/or manage it. This follows from the conceptual framework for undertaking environmental risk assessments developed by Hart *et al.*, (2005) (Figure 34).

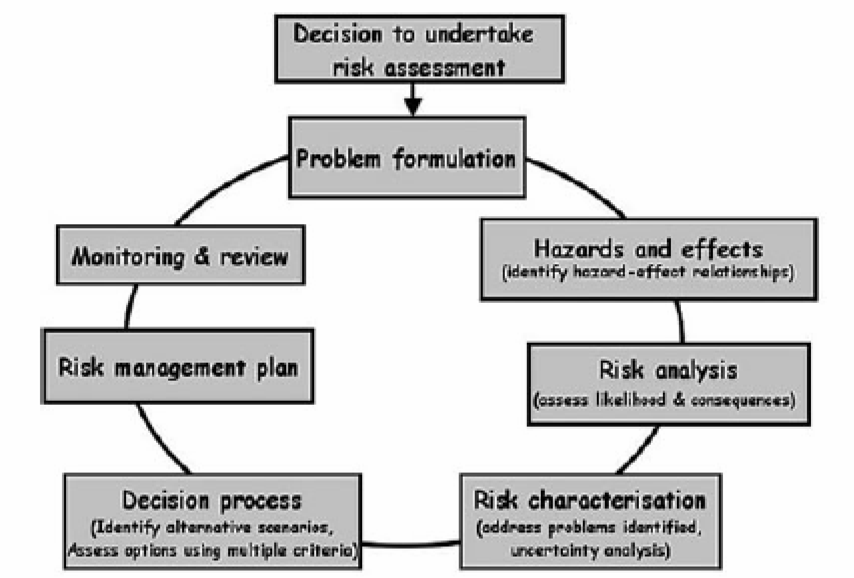

Figure 34. Conceptual framework for undertaking environmental risk assessments (Hart *et al*., 2005).

4.2 Potential benefits

The environmental benefits associated with composting as an option for managing aquatic weeds removed from waterways are two-fold.

Firstly, composting diverts organic material from landfills and avoids environmental impacts associated with the decomposition of organic material, in particular leachate and methane production. Composting is also preferable to other management options such as incineration, which impacts on air quality through generation and emission of greenhouse gases, particulate material and toxins.

Secondly, the final composted product can be used to increase ground cover, reduce runoff and minimise soil erosion from the areas of the Hawkesbury-Nepean Catchment which reduce downstream water quality and contribute to aquatic weed outbreaks.

4.3 Conclusions and recommendations

This research has demonstrated composting is an effective method of managing the organic material removed from waterways as part of aquatic weed control operations. It has also confirmed the resulting compost can be beneficially re-used to improve land condition in degraded catchments. However, composting, like other management options, such as burial or incineration, has environmental risks associated with it. The principal risk of concern is the potential for alligator weed to survive the composting process and spread on land. Consequently, it is recommended land application of the compost derived from the present investigation be restricted to catchments where alligator weed is already present or has a low risk of infesting riparian areas.

The risk associated with weed survival in future composting operations could be reduced by optimising the composting process though:

- constructing a hard stand which will enable adequate turning and mixing all of the material;
- adding feedstock, such as source separated garden organics, to increase the temperatures within the windrow to enable more complete thermophilic decomposition (>45°C) and pasteurisation (>55°C);
- extending the period of exposure, by increasing the number of compost phases from 4 to 5;
- Using temperature probes and data logging devices (temperature data loggers) to ensure required temperatures are achieved; and
- Monitoring the windrows and adjacent areas for the presence of Alligator Weed and other weeds and conducting prophylactic spraying when necessary.

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6 APPENDICES

6.1 Appendix 1: Stakeholders consulted in the development of and during the project

Stakeholder	Roles and responsibilities
Department of Environment and Climate Change NSW (DECC)	▪ Environmental regulator, responsible for protecting air, land and water quality under the Protection of the Environment Operations Act 1997). ▪ Promoter of resource recovery under the Resource Recovery Act 2001.
The Hawkesbury-Nepean Catchment Management Authority (HN CMA)	▪ Catchment manager
NSW Department of Primary Industries (DPI)	▪ Responsible for coordinating and managing noxious weeds (terrestrial and aquatic) under the Noxious Weeds Act (NSW Agriculture 1993). ▪ Responsible for undertaking research into the beneficial reuse of recycled organics.
Bettergrow Pty Ltd	▪ Commercial partner engaged to undertake the composting operation.
Hawkesbury City Council	▪ Local government ▪ Owner and operator of facility (Hawkesbury City Council Waste Management Facility (HCCWMF)) where composting was undertaken.

6.2 Appendix 2: Key outcomes and deliverables arising from this project

6.2.1 Outcomes

- 70,000 m^3 of organic material diverted from landfill
- Currently 2,000 m^3 of composted soil conditioner produced for beneficial reuse, with an additional 2,000 m^3 in production.
- Improved understanding of the risks and benefits associated with compost prepared from harvested aquatic weed.
- Recommendations for managing the risks associated with compost prepared from harvested aquatic weeds.

6.2.2 Deliverables

The deliverables arising from this project include a field day, an environmental report, education and extension communications and a conference paper. In addition, two manuscripts for submission to peer reviewed scientific journals are currently being prepared.

Field Day

The outcomes from the project were presented on July 28 at a seminar at Belgenny Farm. Approximately 50 people attended the field day including representatives from catchment management authorities, councils, Sydney Water Corporation, the DECC, Department of Lands and other branches of the DPI. After the field day, many of these stakeholders expressed their interest in pursuing composting as a new solution for managing organic material harvested from waterways. The field day was publicised in *Agriculture Today* (See below).

Environmental report

- Dorahy, C.G., McMaster, I., Pirie, A.D., Muirhead, L., Pengelly, P and Chan, K.Y. (2007). Risks and benefits associated with using compost prepared from harvested aquatic weed for improving land condition in the Hawkesbury-Nepean Catchment. Final report prepared for the Department of Environment and Climate Change (NSW), November 2006.

Education and Extension Communications

- Arblaster, J. (2006). Innovative researchers turn curse into compost. *Hawkesbury Independent*, 19 September 2006. Fairfax Community Newspapers, Richmond, NSW.
- Dorahy, C., McMaster, I., Pirie, A., Muirhead, L. and Chan, Y. (2006) Preparing compost from aquatic weeds removed from waterways. *Primefact* **229**, NSW Department of Primary Industries, Orange, NSW (www.dpi.nsw.gov.au/aboutus/resources/factsheets/primefacts/compost-aquatic-weeds).
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- Finlay, J. (2006) Aquatic compost OK. *Agriculture Today*, September 2006 edition, NSW Department of Primary Industries, Orange, NSW.

Conference Paper.

- Dorahy, C.G, McMaster, I., Pirie, A.D., Muirhead, L.M., Pengelly, P., Chan, K.Y. and Jackson, M. (2007). Risks and benefits of using aquatic weed compost for improving land condition in the Hawkesbury-Nepean Catchment. *Proceedings of OzWater '07*, March 2007, Sydney Convention and Exhibition Centre, Sydney, NSW. Australian Water Association.

This paper has been peer reviewed and selected for an oral presentation at the conference.

Peer reviewed scientific journal papers

- Dorahy, C.G, McMaster, I., Pirie, A.D., Muirhead, L.M., Pengelly, P., Chan, K.Y. and Jackson, M. (In Prep). Risks associated with compost prepared from aquatic weeds removed from waterways. To be submitted to the *Journal of Environmental Quality*.
- Dorahy, C.G, McMaster, I., Pirie, A.D., Muirhead, L.M., Pengelly, P., Chan, K.Y. and Jackson, M. (In Prep). Erosion control performance of compost prepared from aquatic weeds removed from waterways and source separated garden organics. To be submitted to the *Journal of Soil and Water Conservation*.